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JOURNAL OF THE BOSTON SOCIETY OF CIVIL ENGINEERS

**Volume XXIX
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THE HYDRAULICS OF THE NEW PRESSURE AQUEDUCT OF THE METROPOLITAN WATER DISTRICT

(Presented at a meeting of the Hydraulics Section, Boston Society of Civil Engineers,
held on November 18, 1941.)

BY KARL R. KENNISON, MEMBER*

THE construction of the new pressure aqueduct and its proposed extension to the centers of distribution accomplishes four main objectives:

First, it eliminates various sources of pollution by making it possible to use in the regular operation of the system only the best sources, reserving the Sudbury source as an important emergency standby and the old Cochituate source as one for more remote emergency use, at the same time making it unnecessary to continue in regular use the very old grade-line aqueducts which receive a great deal of pollution from inflows en route. This matter is only mentioned in passing. It is fully covered in a legislative report published as House Document No. 262 of the year 1938.

Second, it gives immediate relief in the shape of additional carrying capacity of the supply mains which feed the District from the terminal chamber of the Weston Aqueduct. Three large supply mains now leave this terminal chamber. The first of these has two 60-inch steel branches, one running northeasterly through Waltham and Belmont to Arlington and the other a little north of easterly through Newton to Brighton. The other two supply mains extend easterly

*Chief Engineer, Metropolitan District Water Supply Commission, 20 Somerset Street, Boston, Mass.

along Commonwealth Avenue, Newton, to Chestnut Hill, one a 60-inch and one a 48-inch pipe incapable of safely withstanding any important increase in pressure. Following our recent installation of new pipe lines in its Sudbury-River and Happy-Hollow siphons the Weston Aqueduct has its full designed capacity of 300 m.g.d., but its delivery has been restricted to about 130 m.g.d. by the inadequacy of these supply mains, the only prospect for the future, except for the new pressure aqueduct, being to add more and more mains in surface locations which are already crowded. The two 60-inch steel mains can safely take the additional pressure from an 84-inch connection which has already been made from a point near the easterly end of the pressure aqueduct, and their capacity is sufficiently increased to permit discontinuing the regular use of the old Sudbury Aqueduct which has always furnished a considerable portion of the demand at the Chestnut Hill pumping station.

Third, the city tunnel which is now to be constructed as an extension of the pressure aqueduct to Chestnut Hill will eliminate the necessity and cost of pumping at that point to the southern high service.

Fourth, this is all designed as a part of a distribution tunnel loop under the principal centers of consumption which will ultimately eliminate the necessity and cost of pumping from the Spot Pond Pumping Station to the Fells Reservoir of the northern high service.

The above will serve to point out the principal considerations which affected the design of the new pressure aqueduct. This was governed primarily by the necessity for obtaining a system with the proper hydraulic characteristics to fit the ultimate plan of eliminating the southern and northern high service pumping.

The cities and towns of the district are scattered over a wide, fairly level area resembling the bottom of a bowl and it is only in the surrounding ring of hills that adequate high service reservoirs can be found; for example, in the Middlesex Fells, in Weston and in the Blue Hills. In addition, the high ground near Chestnut Hill furnishes several meager sites. The district had already developed the Fells Reservoir on the northern high service and obtained control of a considerable area of surrounding land. The Metropolitan District Water Supply Commission incidental to its recent program of new construction, enlarged this reservoir from an area of 8.5 acres to 20 acres,



FIG. 1.—DISTRIBUTION SYSTEM AND PROPOSED TUNNEL LOOP.

at the existing elevation, 271 feet above Boston City Base. The enlarged reservoir is thus of immediate service to meet growing needs of municipalities north of Boston. Furthermore, it was found to be neither desirable nor practical to provide a reservoir for future use at any different elevation, although it may be true that with the more adequate distribution capacity which is bound to be in effect when the tunnel loop is completed, a slightly lower average elevation of the fluctuations in this reservoir will be entirely satisfactory.

The needs of the southern high service have to date been inadequately met by the small Fisher Hill Reservoir in Brookline which is about 20 feet lower, or elevation 251. As a part of its recent new construction the Commission selected a suitable site in Weston and constructed a new high service distributing reservoir called Norumbega Reservoir, the maximum elevation of which is fixed by a spillway at 274.5.

OPERATION OF WESTON AQUEDUCT SUPPLY MAINS UNDER VARIOUS CONDITIONS
CAPACITY FLOW WITHOUT THROTTLING

	<i>Approximate Million Gallons Daily</i>			Total	Total in Weston Aqueduct*
	60" Steel to Arlington	60" Steel to Brighton	60" and 48" C. I. in Com. Ave.		
<i>Without benefit of Pressure Aqueduct connection</i>	32	35	60	127	127
<i>With Pressure Aqueduct connection to one steel main</i>	54	31	60	145	91
<i>With Pressure Aqueduct connection to two steel mains</i>	51	64	60	175	60
<i>With City Tunnel to Chestnut Hill and connection to one steel main</i>	55	35	60	150	95
<i>With City Tunnel to Chestnut Hill and connection to two steel mains</i>	52	65	60	177	60
<i>With Future Tunnel Loop Completed. Could connect to one or two steel mains same as above, or could also connect to neither of them as follows: the Belmont Pumps being supplied by a connection directly from the north loop.</i>	30	35	60	125	125

*The weekly rate of supply through Weston Aqueduct itself will be less than this maximum due to such storage fluctuation in Weston Reservoir as results from any variation in the draft through the supply mains.

These two distributing reservoirs, Norumbega Reservoir located where the pressure aqueduct enters the district proper, and the Fells

Reservoir located approximately at the other extremity to the north-east, are fundamentally important features of the system. Being located on opposite sides of the tunnel loop they are ideally situated to serve the District's future needs. Both will be connected to the loop through double or 2-waterway shafts so that they both can be kept riding on the system regardless of the necessity for unwatering any section of the tunnel.

For the purpose of such unwatering and emergencies, the westerly portion of the loop will drain to the bottom of an unwatering shaft at the Charles River in Weston, Shaft No. 5, and the easterly portion to the bottom of an unwatering shaft at tidewater in Charlestown, Shaft No. 11. The south branch of the loop will be divided for the purpose of such drainage by a double shaft in Jamaica Plain, Shaft No. 8, and the north branch of the loop by a double shaft in Somerville, Shaft No. 13.

Although it would have been possible to obtain a much greater head by starting the new pressure aqueduct at Wachusett Dam, the cost was prohibitive, and entirely unwarranted in view of the excellent condition and carrying capacity of the Wachusett Aqueduct which brings a supply from Wachusett Dam to a terminal chamber in the Town of Southborough. This is a grade line aqueduct and the intrados of its arch at the outlet is about Elev. 278.1. The fact that this is only about 7 feet above the elevation of the Fells distributing reservoir at the northeasterly extremity of the water district is a fundamental consideration in the design of the pressure aqueduct and explains its large diameters. Obviously, it was necessary to crowd this available head as much as possible by raising the elevation to the extreme practicable limit at the upstream end. The weight of the masonry arch of the Wachusett Aqueduct and its earth cover is such that it was possible to raise the maximum hydraulic gradient at the terminal chamber to a level 2 feet above the intrados, the governing consideration being not so much the amount of pressure that could be added under the earth-covered arch as the weight of the ceiling over the waterway at the Assabet Bridge, about 12,500 feet upstream from the terminal chamber. The brick lining of the waterway across this bridge was found to be in excellent condition except for horizontal cracks near the ceiling. As a part of the pressure aqueduct construction, this lining was tightened by a coating of gunite on bottom, sides and top

to prevent any leakage under very slight pressures, which, however, will never be sufficient to equal the weight of the masonry ceiling which forms the floor or walkway over the top of the bridge.

Another fact that had to be considered in this connection was the loss of head at the terminal chamber itself which was never designed for the condition of high backwater now desired. The flow discharged through three submerged archways in the building wall into the upper end of the open channel which has flowed into Sudbury Reservoir. It was discovered when the contractor built the pressure aqueduct intake across this open channel about 2,450 feet below the terminal chamber, that when the water level in the open channel was raised abnormally, the flow out of the end of the aqueduct impinged on the opposing curtain wall above the arches in such a way as to cause excessive eddying and a considerable loss of head in getting through the archways. In fact, the observations indicated that the loss of head from this cause alone would be approximately twice the velocity head through the archways which had about 70 square feet of opening. The approach and getaway from the existing openings could have been altered by permanent reconstruction of the masonry so as to materially improve the flow conditions or, at probably less cost, the entire wall could have been reconstructed with a single large opening. However, since the recovery of velocity head downstream from the openings appeared to be satisfactory as judged by the observed slight rise in water level and since the trouble seemed to be almost entirely in the entrance condition it was decided to smooth this up by merely lowering in existing stop log grooves in front of each of the three archways, trumpet shaped, thin steel plates which provide a smooth approach to the archway.

The open channel below the terminal chamber provided a ready means of obtaining the necessary equalizing basin between the grade-line Wachusett Aqueduct with its fairly constant flow and the pressure aqueduct with its flow subject to much more rapid changes by the gate regulations. The upper end of the open channel was converted into such an equalizing basin with an area of about 5 acres by constructing a diversion dam across it at a point about 2,450 feet downstream from the terminal chamber and by diverting the natural drainage on both sides so that it would enter the open channel below the diversion dam. The diversion channel on the south side drained a large,

swampy area and the banks of the new basin were raised to insure the effectiveness of its exclusion under any flood condition. The bank on the north side also had to be raised, partly to relocate a service roadway, and the diversion channel on this north side was required to pass through an inverted siphon culvert beneath the pressure aqueduct itself just below the intake.

In order to increase the available head on the new pressure aqueduct as much as possible as above described, the crest of the spillway of the diversion dam at the pressure aqueduct intake was constructed at Elev. 278.50, thus fixing at that elevation the normal hydraulic gradient at the intake.

The following table shows the resulting backwater effect under different conditions of operations:

M.G.D. Flowing in Wachusett Aqueduct	300	300	300	325	325	325
M.G.D. Diverted through Pressure Aqueduct	300	250	200	300	250	200
Balance over Intake Spillway	0	50	100	25	75	125
Hydraulic Gradient at Assabet Bridge in feet above (+) or below (—) the intrados	— .65	— .20	+ .05	+ .35	+ .65	+ .85

Although the head now available between the Wachusett Aqueduct Terminal Chamber and the distributing reservoirs of the District is limited as above stated, the design has taken into account not only provisions for a second surface line paralleling the first, east of Sudbury Reservoir, but also the possible desirability of increasing the available head by a future extension to Wachusett Reservoir from the extreme upper end of the present pressure aqueduct. In studying the location of such an extension, we took into account the fact that it might be necessary, in the more remote future, to construct a filtration plant somewhere along this line capable of filtering the entire supply. A suitable location was selected with a workable hydraulic gradient allowing for the loss of head through filters, etc., and a sufficient drop from the Wachusett Dam outlet where the elevation of the tailwater from the turbines might be set at about Elevation 330. This means that the head on the Pressure Aqueduct could in the future be multiplied by nearly four, thus nearly doubling the capacity. However, such a quantity of water could be consumed only by a district expanded considerably beyond present limits, and the distribution system would

be radically enlarged, for example to include a distribution reservoir in the Blue Hills to the south. The Design has been based on such a possible future hydraulic gradient, and the free air vent at the dwtake Shaft No. 1 to the tunnel under Sudbury Reservoir and the emergency spillway at the top of Shaft No. 3 have been constructed to permit future vertical extension to the new gradient. Details of the design are fully covered in current literature, particularly a paper entitled "Design of the Construction of the Pressure Aqueduct", by Assistant Chief Engineer, Stanley M. Dore, presented last December before the New England Water Works Association, and a paper entitled "Design of Fabricated Plate Steel Tees, Laterals and Wyes of Large Diameters for the Pressure Aqueduct", by Chester J. Ginder and Edwin B. Cobb, presented last November before a Section Meeting of this Society.

Starting at the intake, a length of 9,680 feet is of almost unprecedented size for this type of precast cut-and-cover construction, 12' 6" diameter. There are two reasons for this: first, the topography was such that the flat hydraulic gradient obtained with the large diameter made possible a much greater length before the depth of cut made it necessary to go into the tunnel which was constructed, 14' in diameter, for an additional length of 15,820 feet beneath high ground in Southborough and beneath the Sudbury Reservoir; second, this entire length of nearly five miles is large enough so that it will never have to be paralleled by a second surface line, or tunnel.

Large-diameter wyes referred to in the above-mentioned paper are provided not only at the extreme upper end of the new Pressure Aqueduct but also at the top of the dwtake Shaft No. 1 leading to the tunnel under the Sudbury Reservoir so that any future extension to Wachusett Reservoir can be made from either point.

The entrance to the Pressure Aqueduct at the diversion dam is designed so that if and when such an extension to Wachusett Reservoir is made then there can be substituted for the present arrangement of stop logs a plug of reinforced concrete containing back-pressure sluice gates capable of taking the increased head from Wachusett Reservoir while at the same time permitting diversion from the intake reservoir as at present.

The service line east of the uptake Shaft No. 4 is generally 11' 6" diameter, about 58,600 feet to Norumbega Reservoir and about

10,400 feet to the downtake Shaft No. 5 entering the city tunnel and the future tunnel loop. Other large-diameter wyes, etc., similar to those above referred to are provided to make it possible in the future to parallel the entire length with a second 11' 6" pipe. However such paralleling is more probable in the case of the shorter length above referred to since a second service line east of Norumbega Reservoir is expected to be constructed when the tunnel loop is completed so as to provide a direct connection between Norumbega Reservoir and both branches of the loop, in effect making the loop extend westerly to the reservoir itself. However, it is possible that neither the increase in consumption nor the sums available for such new construction may warrant such a second service line.

Another provision which was made in the design of the aqueduct consists of four 42" outlets, two on each side of a control valve in a branch of the 84" connection from the Pressure Aqueduct to the Weston Aqueduct supply mains, extending to the Weston Aqueduct terminal chamber. These outlets can later, if desired, serve as suction and discharge for a booster pump which can lift water from the Weston Aqueduct grade, Elev. 200, about 70 feet to the Pressure Aqueduct grade. Such a pump could not only supply the high service in an emergency independently of the Pressure Aqueduct but might be a very economical substitute for a second 11' 6" line paralleling the Pressure Aqueduct in case the future consumption requirements showed occasional small increases in the demand sufficient to crowd the capacity of the system, but hardly sufficient to warrant new construction on a large scale.

Hydraulic characteristics of the system including the future tunnel loop are briefly summarized in an accompanying diagram. This does not include a consideration of all future possibilities above discussed but does assume the completion of the entire tunnel loop together with a second 11' 6" line east of Norumbega Reservoir. This diagram also shows the approximate distribution of the high service and low service consumption in the vicinity of the different shaft heads on the assumption that the high service will increase from the present 50% of the demand in the district proper to about 55%. It will be necessary to supply by bleeding from the high service at various points in the district whatever shortage results from lack of capacity in the Weston Aqueduct supply mains or impracticability

Hydraulic Characteristics of the

Future Tunnel Loop

Figures below the line = Friction Loss in Feet per unit Flow of 1 mgd.

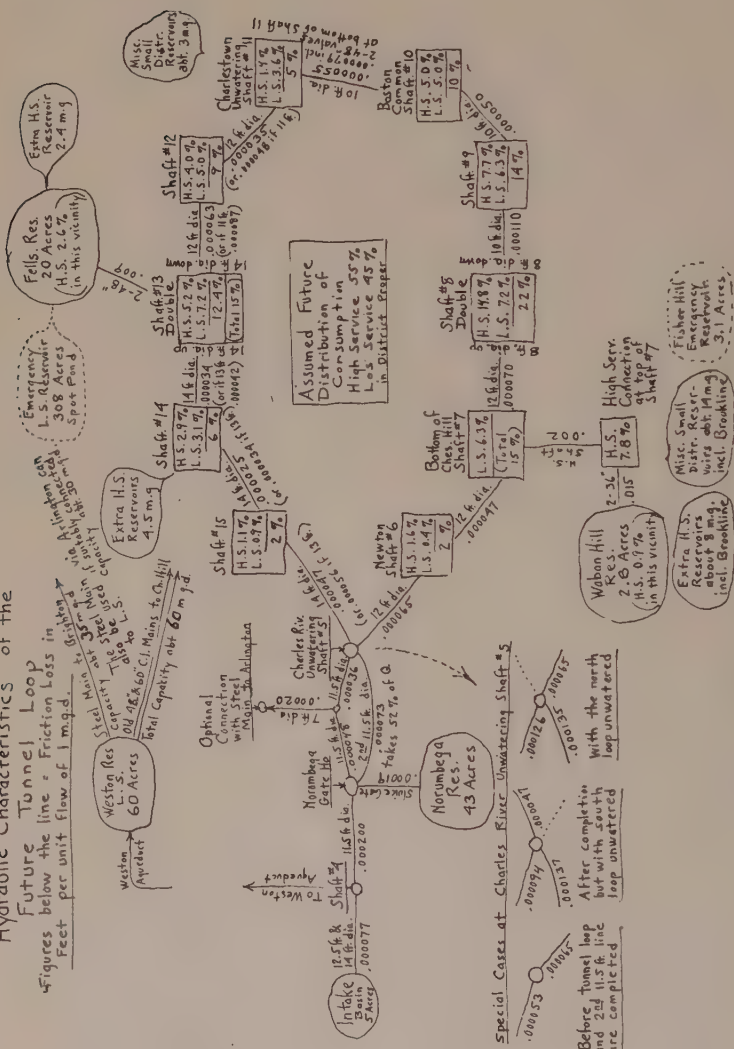


FIG. 2.—HYDRAULIC CHARACTERISTICS OF THE SYSTEM.

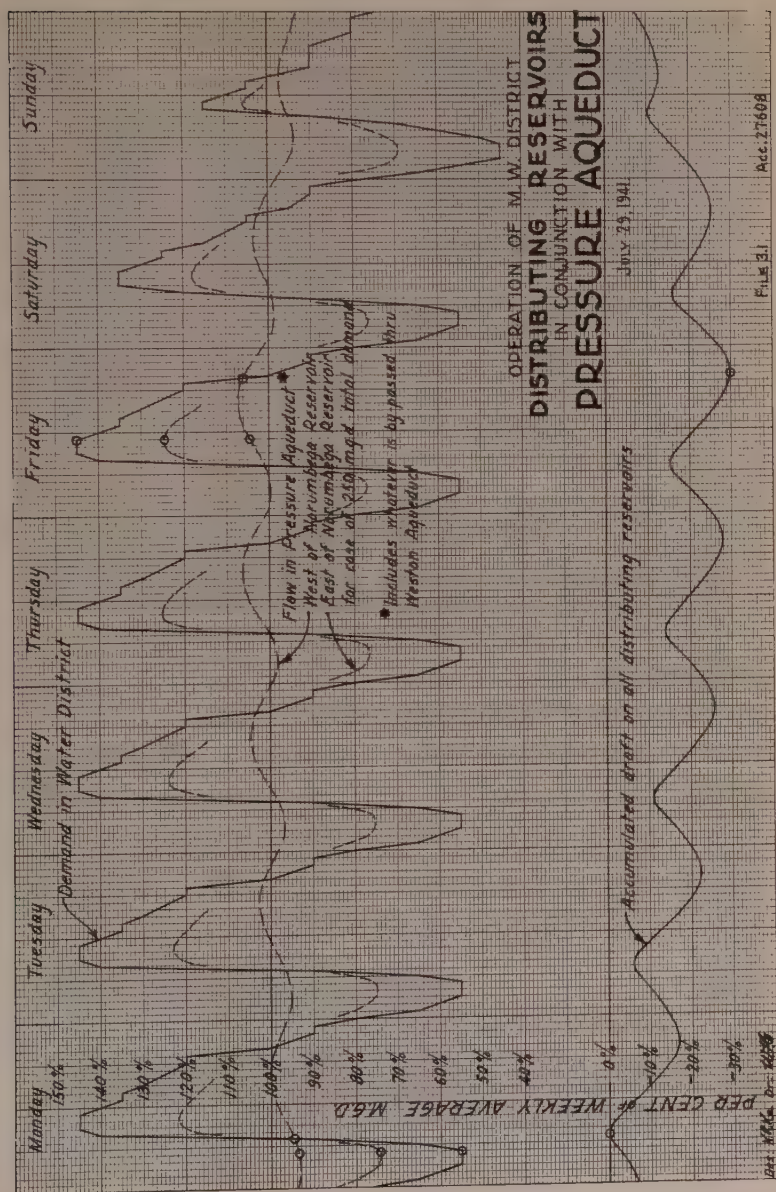


FIG. 3.—ANALYSES OF WEEKLY FLUCTUATIONS.

DATA FOR COMPUTING TUNNEL-LOOP GRADIENTS
CASE OF 250 M.G.D. WEEKLY AVERAGE DEMAND
ASSUMED DISTRIBUTION OF CONSUMPTION OF 244 M.G.D.
IN THE DISTRICT PROPER

	Weekly Fluctuations in Distribution Reservoirs	Weekly Average				Four Critical Times in the Week			
		Approximate Location of the Demand		Low Consumption		Maximum Storage in Distributing Reservoirs		High Consumption	
		High Service	Low Service	Monday 5 A.M.	Monday 7 A.M.	Monday 7 A.M.	Friday 11 A.M.	Friday 8 P.M.	Minimum Storage in Distributing Reservoirs
% of Weekly Average	30%	55%	45%	m.g.d.	55%	94½%	145%	106%	m.g.d.
To Low Service, via Weston Aqueduct (Not Using Supply Main to Arlington)	m.g.	m.g.d.	m.g.d.	m.g.d.	m.g.d.	m.g.d.	m.g.d.	m.g.d.	m.g.d.
Weston Reservoir	9				60	95	95	95	
Norumbega Reservoir	35			+26	+47	—9	—9	—9	—9
<i>North Branch of Tunnel Loop</i>						+5	—49		+6
Shaft 15		2.7	2.2		1.5	2.7	5.2		3.3
Shaft 14		7.0	7.6		3.9	7.2	14.6		8.8
Extra High Service Reservoir	2						—3		
Shaft 13		12.7	17.6		7.0	13.4	28.8		17.1
Vicinity of Fells Reservoir		6.3			3.5	5.9	9.1		6.7
Fells Reservoir	16			+12	+5.5	+5.5	—15		+3
Extra High Service Reservoir	1						—2		
Shaft 12		9.8	12.2		5.4	10.2	21.4		12.8
Shaft 11		3.4	8.8		1.9	3.9	10.1		5.4
Miscellaneous Reservoirs	1						—2		

	Weekly Fluctuations in Distribution Reservoirs	Weekly Average		Four Critical Times in the Week			
		Approximate Location of the Demand		Low Consumption	Minimum Storage in Distributing Reservoirs	High Consumption	Maximum Storage in Distributing Reservoirs
		High Service	Low Service				
% of Weekly Average	30%	55%	45%	Monday 5 A.M.	Monday 7 A.M.	Friday 11 A.M.	Friday 8 P.M.
	m.g.	m.g.d.	m.g.d.	m.g.d.	m.g.d.	m.g.d.	m.g.d.
<i>South Branch of Tunnel Loop</i>							
Shaft 6		3.9	1.0	2.2	3.8	6.2	4.2
Shaft 7			15.4		1.2	9.1	3.2
		19.1		10.5	17.9	27.7	20.2
Vicinity of W. H. Reservoir		2.1		1.2	2.0	3.0	2.2
Waban Hill Reservoir	4			+5.5	-1	-7	+0.5
Miscellaneous Reservoir	2					-3	
Shaft 8		36.0	17.6	19.8	35.4	62.5	41.7
Extra High Service Reservoir				+3.5	-0.5	-9	-0.5
Shaft 9	3	18.8	15.4	10.4	18.9	36.4	23.1
Shaft 10		12.2	12.2	6.7	12.5	24.9	15.3
	73	134	110	134 +94	230 ±0	354 -99	259 ±0
				228		255	

of supplying the low service through these existing mains. It is undesirable, and it is hoped that it will be unnecessary to make any further major additions to the low service supply mains since the tunnel now being built at Chestnut Hill and the completion of the tunnel loop, in perhaps fifteen or twenty years, will make it possible to deliver water where it is wanted. To illustrate the operation of the system three cases have been considered corresponding to a total weekly average demand of 200, 250 and 300 m.g.d. It was first necessary to determine the weekly variation in consumption. This was done from a study of the records of several venturi meters, each of which supplies a considerable percentage of the total demand and is located between the distributing reservoirs and the consumers so as to give a fair indication of the actual demand hour by hour. The result is shown on an accompanying graph.

This graph shows not only the variation in demand but, also, the fluctuation in the distributing reservoirs necessary to accommodate the demand. Since we are considering the maximum capacity of the system, we assume that the Weston Aqueduct is used to relieve the pressure aqueduct of a relatively small part of its load, or, specifically, to the maximum extent possible under the limited capacity of the existing Weston Aqueduct supply mains to feed the low service. For example, in the case of the high rates of consumption used in these estimates, the three Commonwealth Avenue and Brighton mains can supply the entire low service in some of the off-peak hours but at other times a considerable portion of the low-service demand will have to be met by bleeding from the high service.

The fundamental reason for this is a lack of adequate low-service reservoirs in the District proper. Weston Reservoir, although it will continue in regular use, is too remote and will fluctuate less and less as the consumption increases. Following the recent construction of a by-pass around its shores, Spot Pond is, for sanitary reasons, not regularly used, but on account of its size, 308 acres, and strategic location, it should always be kept as an important reserve. Its elevation is a little too low to continue to ride satisfactorily on the low service.

The diagram of weekly fluctuations shows four critical periods which have been analyzed in the case of the 250 m.g.d. demand to illustrate the operation of the system. They are as follows: on

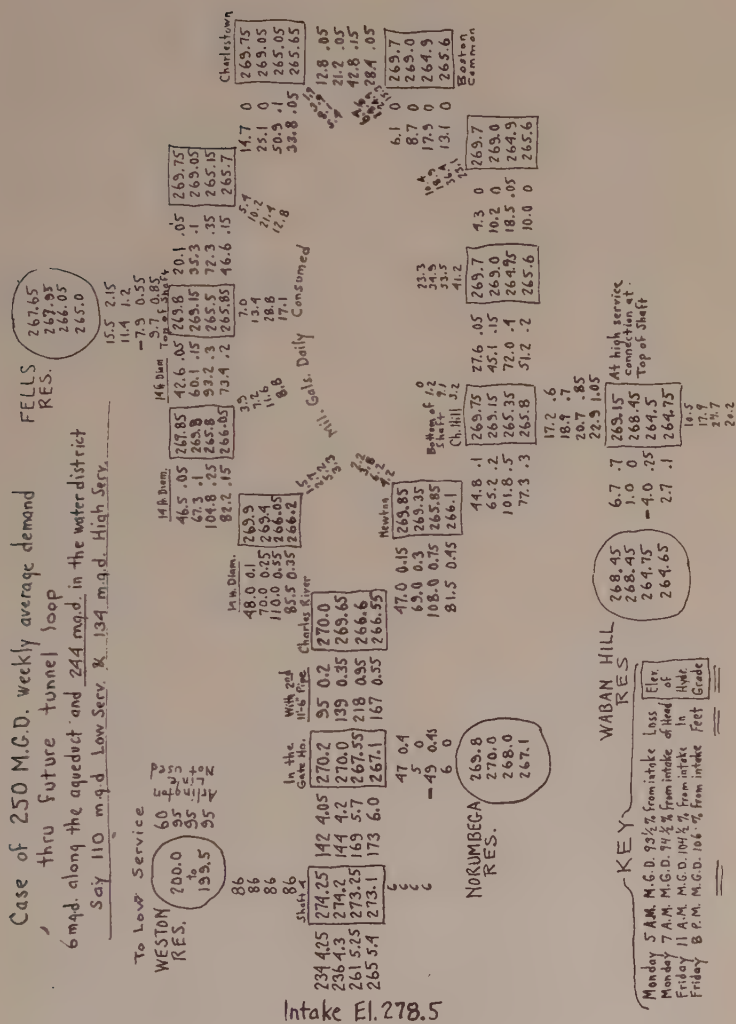


FIG. 4.—CASE OF 250 M.G.D. WEEKLY AVERAGE DEMAND THROUGH FUTURE TUNNEL LOOP.

Monday at about 5 A.M., we have a combination of low rate of consumption and high distributing reservoir levels; on Monday at about 7 A.M., the distributing reservoirs as a whole are at their maximum levels; on Friday at 11 A.M., we have a combination of high rate of consumption and low reservoir levels; on Friday at about 8 P.M., the reservoirs as a whole are at their minimum levels. One of my computation sheets summarizes for each of these four critical times: the flow in the Weston Aqueduct supply mains, the flow to or from the distributing reservoirs and the demand in the vicinity of each shaft head, taking into account the necessity above referred to for bleeding from the high service to the low service. It also includes an estimate of the weekly fluctuation in each of the distributing reservoirs which is used to finally check the computations of hydraulic gradients at these four critical times, which are summarized on another computation sheet.

A computation of this sort shows the general trend of fluctuations throughout the week as the gradients are whipped up and down in response to the demand and subject to the dampening effect of the distributing reservoir areas. Furthermore, once these fluctuations are understood, it is evident that we can confine our attention to only two critical times, the second and fourth above-referred to, when the distributing reservoirs are at their maximum and minimum levels respectively, and that we can compute distributing reservoir fluctuations without reference to the other two times of low and high demand. Such abbreviated computations are illustrated in the cases of 200 and 300 weekly average m.g.d. In all the computations in addition to Norumbega Reservoir and Fells Reservoir, which are by far the most important equalizers on the tunnel loop, the effect of Waban Hill Reservoir is also indicated. Its operating level is now Elevation 264.5, but it should be possible to raise this a few feet and it may be found desirable to do so.

Considerable flexibility is possible in the method of operating the pressure aqueduct so as to permit the maximum generation of electric power at Wachusett Dam in the hours when it is most valuable. This applies particularly to conditions at present and in the near future as distinct from the situation which was studied to determine the capacity of the system in the future with high rates of consumption. For example, if we take the case of a total demand of only 165 m.g.d.

SUMMARY OF FLUCTUATIONS OF THE PRINCIPAL DISTRIBUTING RESERVOIRS UNDER
CONDITIONS OF FUTURE OPERATION AFTER COMPLETION OF
THE DISTRIBUTION TUNNEL LOOP

Total Demand, weekly average	200 m.g.d.	250 m.g.d.	300 m.g.d.
Consumed in the District Proper	195 m.g.d.	244 m.g.d.	293 m.g.d.
By-passed to low Service through Weston Aqueduct:			
Before the Arlington line is adjusted to Low Service use exclusively	79 m.g.d.	86 m.g.d.	
Using the Arlington line			110 m.g.d.
<i>Weekly Fluctuation in Principal</i>			
High Serv. Distributing Reservoirs:			
<i>If second 11' 6" line from Norumbega Reservoir to Charles River is built, as planned, with the tunnel loop:</i>			
Norumbega (Spillway El. 274.5)	El. 273.6 to 271.8	El. 270.0 to 267.1	El. 266.7 to 262.8
Per Cent of Storage Remaining	85%	63%	46%
Fells (Normal H.W. El. 271)	El. 272.4 to 270.2	El. 268.0 to 265.0	El. 264.2 to 260.0
Per Cent of Storage (to 271) Remaining	94%	58%	31%
Waban Hill (Normal H.W. El. 264.5, could be raised)	El. 272.6 to 270.2	El. 268.5 to 264.6	El. 264.0 to 259.3
<i>If second 11' 6" line from Norumbega Reservoir to Charles River is NOT built:</i>			
Norumbega (Spillway El. 274.5)	El. 273.5 to 271.8	El. 269.9 to 267.2	El. 266.6 to 262.9
Per Cent of Storage Remaining	85%	63%	47%
Fells (Normal H.W. El. 271)	El. 271.7 to 269.4	El. 266.6 to 263.4	El. 262.4 to 257.9
Per Cent of Storage (to 271) Remaining	88%	49%	26%
Waban Hill (Normal H.W. El. 264.5, could be raised)	El. 271.9 to 269.3	El. 267.1 to 263.0	El. 262.1 to 257.1

or 160 m.g.d. in the District proper, the system will operate satisfactorily if the discharge from Wachusett is concentrated at a rate well within the limits of safety at Assabet Bridge, namely 300 m.g.d. in say 102 hours a week, two shifts of 16 hours, from 7 A.M. to 11 P.M. Monday to Friday, inclusive, a somewhat shorter period of say 14 hours on Saturdays, and say one shift of 8 hours on Sundays and holidays. This illustration of special conditions of operation with a rather low rate of consumption would apply equally well with the future tunnel loop completed or with only the extension from Shaft No. 5 to Chestnut Hill, but the latter would actually be the case for

practical consideration under such a low rate of discharge as 160 m.g.d., since the average weekly consumption will undoubtedly reach this figure before the tunnel loop is completed.

With the tunnel extending to Chestnut Hill only, its use is practically limited rather definitely to the consumption in the southern, intermediate and southern extra high services, which would amount to about 60 m.g.d. out of a total demand in the District of 160 m.g.d. Add to this about 32 m.g.d. which would be discharged from the pressure aqueduct through the 84-inch connection to the northerly Weston Aqueduct supply main to make the new high pressure available at the Belmont pumping station and in Arlington and to maintain about the present rate bled from this main northerly toward Spot Pond and we obtain 92 m.g.d. as the total passing through Norumbega Reservoir, leaving a balance of 68 m.g.d. through Weston Reservoir by way of Weston Aqueduct.

Under such an arrangement, the flow from Wachusett would be stopped entirely at night except that a small flow of something like 30 m.g.d. could be allowed to run from Wachusett to Norumbega Reservoir during the long weekend shutdown Sunday afternoon and night to prevent too great a draft on Norumbega Reservoir. Too great a fluctuation of the low-service Weston Reservoir could be prevented by a similar light draft through Weston Aqueduct from Sudbury Reservoir using thereby some of the water wasted previously during the week in the small and varying rates of discharge over the spillway of the diversion dam at the pressure aqueduct intake.

By this scheme, the pressure aqueduct gates at Shaft 4 would be opened wide every morning and at the same time the throttling gates on the by-pass at this shaft from the pressure aqueduct would be opened so as to allow a constant rate of say 107 m.g.d. to enter the Weston Aqueduct, leaving the balance to continue by way of the pressure aqueduct at rates varying from about 135 to 155 m.g.d. subject to the head which fluctuates during the day between the spillway at the intake and the rising level in Norumbega Reservoir.

Under such an arrangement the daily fluctuations in Norumbega Reservoir would be greater than with a continuous 24-hour inflow and their direction would be reversed, that is, Norumbega and Weston Reservoirs would start on Monday morning to rise from their lowest weekly level instead of starting at that time to drop from their highest

weekly level. However, all the other distributing reservoirs in the District, accounting for possibly one-third of the aggregate fluctuations, would continue to fluctuate in the normal manner, up Monday morning and down Friday night. As a result, the peculiar fluctuations in Norumbega Reservoir above referred to would be practically doubled in extent. However they would still be well within bounds and would, for example, total only about 2.6 feet in the case of 160 m.g.d. demand used above for illustration.

With increased consumption in the District, it would of course be necessary to discharge more and more water from Wachusett in the hours when the electric power generated is of less value, until finally the capacity of the system is reached with continuous flow in the aqueduct.

One important consideration in the design of the pressure aqueduct is the possibility of using it under a gradient lowered about 15 feet in an emergency resulting in complete discontinuance of the Wachusett supply. In such a case, Sudbury Reservoir, from now on the District's principal reserve storage reservoir, could be turned into the pressure aqueduct and although Fells Reservoir would be reduced to extremely low levels, Fisher Hill Reservoir in Brookline, the principal reservoir on southern high service until the tunnel to Chestnut Hill is completed, would be at just the right level to ride on the reduced gradient, and this reservoir should be maintained for such emergency use. When the Norumbega Reservoir was built, advantage was taken of the topography surrounding an existing area known as Schenck's Pond, to construct a supplementary reservoir at a level about 21 feet lower than that of the main basin. This not only is a valuable reinforcement of the main basin but would be particularly valuable in the case of the emergency above referred to, when the lower Norumbega basin and Fisher Hill would ride on the system.

It should be clear from the above analysis of the various methods of operating the system, that the pressure aqueduct does not in any sense supersede the Weston Aqueduct. This latter grade-line aqueduct is in excellent condition and its capacity is as already stated 300 m.g.d., nearly as much as that of the Wachusett Aqueduct which brings the supply from Wachusett Reservoir to the new pressure aqueduct intake. The Weston Aqueduct is not only capable of reinforcing the pressure aqueduct in the several ways already indicated,

but it should always be retained as a major reserve unit. It will not only feed the four existing supply mains but the flow in the new 84-inch connection from the pressure aqueduct can be reversed so that the Weston Aqueduct could feed directly into the City Tunnel and the future loop if some extreme emergency should make this necessary.

As already stated, the Chestnut Hill pumping station will be discontinued from regular use in the near future as soon as the City Tunnel now under construction can be extended to that point. However, this does not mean that Chestnut Hill Reservoir or the pumping station should be abandoned at that time since such abandonment would leave the District dependent entirely on the uninterrupted operation of one tunnel. It is true that the City of New York, before it completed its loop by the construction of the easterly branch through Queens and Brooklyn, relied entirely on its first single tunnel. Nevertheless, it would be unwise not to keep the works at Chestnut Hill for emergency use until the tunnel loop is completed.

The Spot Pond pumping station must be continued in regular operation until the tunnel loop is completed and an adequate branch line extended to Fells Reservoir so that this valuable equalizer can ride on the system at the future gradient. Even when this is accomplished, the works at Spot Pond should always be maintained for emergency use. The pond itself is a very large body of water and high enough to supply the low service in Boston by gravity. On that account it will continue to be much more valuable than Chestnut Hill Reservoir. Its size and location would make it a valuable permanent asset even without the pumping station. It is also conveniently near Fells Reservoir and in any emergency which would put a portion or all of the tunnel loop itself out of commission, the pumps could always be used to supply the northern high service.

FLOW CHARACTERISTICS OF PIPE LINES, WITH SPECIAL REFERENCE TO THE NEW PRESSURE AQUEDUCT OF THE METROPOLITAN WATER DISTRICT

BY WILLIAM F. COVIL, MEMBER*

INTRODUCTION

IN CONSIDERING the flow through a pipe line or aqueduct of a certain size or a series of pipe lines or aqueducts, it is convenient to analyze the head loss of the line for all its component parts, such as bends, valves and other pertinent structures where losses occur, and reduce this to the basis of the head loss for a unit quantity, as, for instance, the head loss in feet for a flow of one million gallons daily or one cubic foot per second; which might be called, perhaps for want of a better term, the "flow characteristic" or "friction characteristic" of the lines.

DERIVATION OF THE FORMULAE FOR OBTAINING THE FLOW CHARACTERISTIC

A consideration of the fundamental Darcy formula for flow of water through a conduit of $h = f \frac{L V^2}{D 2g}$ and many other formulae for flow will show how this "flow characteristic" may be readily obtained for varying flow in a pipe line where the length and diameter are constant.

By grouping the constant factors, the above formula becomes

$$h = C f Q^2$$

and taking into consideration that the friction factor f is a function of the Reynolds number which contains the variable terms Q and kinematic viscosity ν which varies with temperature, and considering the kinematic viscosity to be constant, this equation reduces to the expression

$$h = C Q^n$$

By direct proportion the ratio between the head loss for any

*Assistant Civil Engineer, Metropolitan District Water Supply Commission, 20 Somerset Street, Boston, Mass.

quantity Q and the head loss for unit quantity Q_1 would result in the equation

$$h_{Q1} = \frac{h}{Q^n}$$

since $Q_1^n = 1$ and the constant factor C cancels out.

The term h_{Q1} is the head loss for unit quantity and is the "flow characteristic", k_f .

$$k_f = \frac{h}{Q^n} \quad (\text{Equation 1})$$

$$\text{and} \quad h = k_f Q^n \quad (\text{Equation 2})$$

For flow in series through various sections of a pipe line for which the value of k_f has been determined for each section,

$$k_{f1} + k_{f2} + k_{f3} + k_{f4} \text{-----} = k_f \quad (\text{Equation 3})$$

or the flow characteristic of the line as a whole.

For divided flow in any portion where the flow again comes back into the main line and where k_f has been determined for each branch, the combined k_f may be determined as follows:

Assume the quantity flowing in each branch to be Q_1 and Q_2 , respectively

$$k_{f1} = \frac{h_1}{Q_1^n} \text{ and } k_{f2} = \frac{h_2}{Q_2^n}$$

therefore

$$h_1 = k_{f1} Q_1^n \text{ and } h_2 = k_{f2} Q_2^n$$

Now

$$h_1 = h_2$$

therefore

$$k_{f1} Q_1^n = k_{f2} Q_2^n$$

and

$$Q_1 = \left(\frac{k_{f2} Q_2^n}{k_{f1}} \right)^{\frac{1}{n}}$$

Now

$$Q_1 + Q_2 = Q_T$$

which is the total quantity flowing in the main line.

Therefore,

$$Q_T = \left(\frac{k_{f2} Q_2^n}{k_{f1}} \right)^{\frac{1}{n}} + Q_2$$

and

$$Q_2 = \frac{Q_T}{1 + \left(\frac{k_{f2}}{k_{f1}} \right)^{\frac{1}{n}}} \quad (\text{Equation 4})$$

or

$$Q_1 = \frac{Q_T}{1 + \left(\frac{k_{f1}}{k_{f2}} \right)^{\frac{1}{n}}}$$

which are the quantities actually flowing in each branch for a total flow of Q_T .

From this, the quantity flowing in each branch for unit quantity flowing in the main line, where $Q_T = 1$, may be obtained

$$Q_2 = \frac{1}{1 + \left(\frac{k_{f2}}{k_{f1}}\right)^{\frac{1}{n}}} \quad (\text{Equation 5})$$

or

$$Q_1 = \frac{1}{1 + \left(\frac{k_{f1}}{k_{f2}}\right)^{\frac{1}{n}}}$$

and hence the flow characteristic for the two lines combined may be obtained directly from

$$k_{fB} = k_{f1}Q_1^n \quad (\text{Equation 6})$$

or

$$k_{fB} = k_{f2}Q_2^n$$

This can now be added in with the flow characteristic for the other sections in Equation 3.

$$k_{f1} + k_{f2} + k_{f3} + k_{f4} + k_{fB} - - - - = k_f \quad (\text{Equation 3-A})$$

For three-way divided flow where the flow again comes back into the main line the proportionate quantities flowing in the three branches for unit quantity flowing in the main line may be determined from the following formulae deduced in the same manner as before:

$$\begin{aligned} Q_1 &= \frac{1}{1 + \left(\frac{k_{f1}}{k_{f2}}\right)^{\frac{1}{n}} + \left(\frac{k_{f1}}{k_{f3}}\right)^{\frac{1}{n}}} \\ Q_2 &= \frac{1}{1 + \left(\frac{k_{f2}}{k_{f1}}\right)^{\frac{1}{n}} + \left(\frac{k_{f2}}{k_{f3}}\right)^{\frac{1}{n}}} \\ Q_3 &= \frac{1}{1 + \left(\frac{k_{f3}}{k_{f1}}\right)^{\frac{1}{n}} + \left(\frac{k_{f3}}{k_{f2}}\right)^{\frac{1}{n}}} \end{aligned} \quad (\text{Equation 7})$$

and the flow characteristic for the three lines combined may be obtained directly as before from Equation 6 by using any one of the quantities and its corresponding flow characteristic; thus it is seen that

in order to obtain the combined flow characteristic for any number of branches, it is only necessary to obtain the proportionate quantity in one branch, first noting the similarity between Equations 5 and 7 and extending the equation.

Where a complicated flow network is concerned it will be ordinarily found that certain parts can be reduced and simplified by application of the foregoing principles and the cut and try computations for the whole or the remainder greatly facilitated by having first established the flow characteristic for each line.

It will be noted that Equation 5 for two branches, and its extension to cover multiple branches, may be applied to the case where waterwheels of different ratings are fed from a common penstock and discharge into a common tailrace.

Equation 5 used in conjunction with Equation 6 furnishes a simple means of applying what Gordon M. Fair has called the "Method of Equivalent Pipes."*

DETERMINATION OF EXPONENT FOR Q TO USE IN CONNECTION WITH PRESSURE AQUEDUCT FLOW STUDIES

Engineers who are in the habit of using the well-known Hazen-Williams formula for flow, obtain this flow characteristic by use of the expression $h = C Q^{1.85}$, which can be reduced from the formula by the substitution of the proper constant factors in the equation $v = c r^{0.63} s^{0.54} 0.001^{-0.04}$ and rearrangement of the terms.

Table 1 gives a list of the exponents of Q deduced from a similar analysis of the formulae of the experimenters noted, for various types of conduits.

It will be noted from Table 1 that Lea and Scobey have devised formulae for the flow of water in concrete pipe lines both of which reduce to the expression $h = C Q^2$, which obviously is more convenient inasmuch as the calculation of head losses for various flows may readily be obtained on the slide rule where the exponent for Q is the square rather than an odd power. The Manning formula for flow also reduces to this expression.

The flow characteristics of the pipe lines comprising the new

*New England Water Assn. journal of June 1941, "Hydraulic Investigation of Water Distribution Systems in Field and Office" by Gordon M. Fair.

TABLE 1—VALUES OF n IN EQUATION $h = CQ^n$

Originator of Formula or Experimenter	Cast Iron	New Cast Iron	Old Cast Iron	Asphalted	New Asphalt Coated	Old Asphalt Coated	Riveted Steel and Analogous	Concrete	Wood Stave and Analogous	All Kinds
Chezy										2.00
Lampe	1.80									
Fanning	2.00									
Reynolds		2.00	1.85							
Unwin		1.95	2.00	1.85			1.87			
Manning										2.00
Flamant										1.75
Tutton	1.96	1.96	1.96		1.81	1.96	1.96		1.96	
Saph-Schoder										1.74
Williams-Hazen										1.85
Williams										1.87
Lea		1.93	2.00	1.78			2.00	2.00	1.80	
Moritz							1.80			
Biegeleisen	1.90						1.80			
Barnes		1.95			1.89				1.73*	
Wegmann-Aeryns	1.86									
Scobey							1.90	2.00	1.80	
Average	1.90	1.96	1.95	1.81	1.85	1.96	1.89	2.00	1.82	1.87

*Average value.

Pressure Aqueduct System were obtained by using the equation

$$k_f = \frac{h}{Q^2}$$

the quantity Q thus having the exponent 2 in line with Lea's Scobey's and Manning's equation, because of their resulting simplicity.

In order to ascertain whether the head loss for a pipe line as large as the pressure aqueduct and the Southborough Tunnel, which were $11\frac{1}{2}$ and 14 feet in diameter, respectively, would actually vary on the basis of the quantity squared or near enough to this relationship so as not to introduce appreciable error, a determination was made as to what the exponent of the quantity would in all probability be, using

as a basis the formula $h = CfQ^2$, as previously noted, by first substituting the known values for the constant factor C , and then eliminating the friction factor " f " from the equation by determining how this factor would vary with the quantity.

It was assumed that the average yearly temperature of the water would be 55° F. and that the kinematic viscosity at this temperature would be $\nu = \frac{.01315 \text{ ft.}^2/\text{sec.}}{103}$, which gives a Reynolds number of

$8,420 Q$. From chart No. 3* there can be found the variation of f with the Reynolds' number and, therefore, with Q using line K on that chart, which is for a concrete pipe 100" in diameter, the nearest approach to the 138", or 11'-6" diameter, pipe which comprises the major portion of the new Pressure Aqueduct system. Assuming various quantities and solving for the Reynolds' number in the equation $Re = 8,420 Q$, the corresponding value of f as obtained are shown in the following Table No. 2:

TABLE 2

Q in c.f.s.	Re	" f "
50	421,000	.0158
100	842,000	.0150
150	1,263,000	.0146
200	1,684,000	.0142
250	2,105,000	.0140
300	2,526,000	.0138
350	2,947,000	.0137
400	3,368,000	.0136
450	3,789,000	.0135

The equation $h = \frac{fL}{D} \frac{V^2}{2g}$ may be rewritten $h = \frac{.0252 fL Q^2}{D^5}$ which can be reduced, by the substitution of 11.5' for the diameter (D) and an assumed length of $L = 1'$ to $h = \frac{fQ^2}{7.98 \times 10^6}$ and assuming the same values of Q as in Table No. 2, the values of $h \times 10^6$ can be obtained, as shown in Table 3:

*Alignment charts for the design of pipe lines by W. F. Covil. New England Water Works Association Journal of March, 1939.

TABLE 3

Q in c.f.s.	Q^2	f	$h \times 10^6$
50	2,500	.0158	4.95
100	10,000	.0150	18.80
150	22,500	.0146	41.17
200	40,000	.0142	71.18
250	62,500	.0140	109.65
300	90,000	.0138	155.64
350	122,500	.0137	210.31
400	160,000	.0136	272.68
450	202,500	.0135	342.58

A plot of the above values of $h \times 10^6$ against the corresponding values of Q on double logarithmic paper gives a straight line and results in the equation $h = CQ^{1.93}$, which was adjudged to be close enough to the square value for the exponent for Q so as not to introduce appreciable error.

DETERMINATION OF THE ESTIMATED FLOW CHARACTERISTICS FOR THE PRESSURE AQUEDUCT SYSTEM

A very brief description of the elements of the Pressure Aqueduct system from the intake at what might be called the Wachusett Aqueduct Terminal forebay to Norumbega Reservoir is as follows: there is approximately 60 feet of Twin Intake section; approximately 9,624 feet of 12'-6" precast concrete bell and spigot pipe manufactured on end using steel forms and laid with extremely smooth cement jointing, on a slope of .02864%; approximately 15,330 feet of 14-foot diameter concrete lined tunnel including the 14-foot diameter downtake at Shaft 1, and a total of approximately 150 feet of 10'-4" and 9'-6" diameter uptake shaft and Venturi section; a divided flow section with 2- and 3-72" Dow valves; approximately 57,250 feet of 11'-6" diameter precast concrete pressure pipe manufactured on end using steel forms and laid with extremely smooth jointing and about 1,120 feet of double horseshoe Twin Aqueduct section, cast in place, each 7'-3" high and 4'-7" wide.

In determining the actual losses through the various elements of the Pressure Aqueduct system a quantity of 400 c.f.s., which is larger than what we would normally expect the Pressure Aqueduct

to carry, was chosen because some of the minor losses would be very small if a small quantity was used, with the tendency of eliminating them from consideration if not carried out to enough places. Estimated friction losses in feet, using this quantity, were carried out to the third decimal place in most instances and to four decimal places where it seemed advisable.

A roughness coefficient to be used in the Manning or Kutter's formula of $n = .012$ was assumed for the main sections of 11'-6" and 12'-6" diameter concrete pipe and of $n = .013$ for the 14' diameter tunnel section. The resulting estimated loss of head for the entire system noted above, using the coefficients mentioned, was about 19.2' for $Q = 400$ c.f.s. which agrees very well with the corresponding loss of approximately 18.7' calculated by stepping up the head loss found from tests to the 400 c.f.s. used in the studies.

The minor losses as estimated, if the losses for the main sections of 12'-6" pipe, 14' diameter tunnel and 11'-6" pipe are deducted from the 19.2' estimated total loss, amounted to about 13% of the total loss.

A typical work sheet showing how the head losses were computed is given. The sheets were mimeographed to save time in rewriting titles and alignment charts were used for determining the head losses by the Manning, Kutter and Scobey formulae with resulting simplicity. The use of more than one formula to obtain this head loss results in an automatic check on the work, and tends to eliminate small differences in reading the charts. Incidentally, it is difficult to make a blunder in reading an alignment chart, as this usually shows up immediately as an absurd answer.

Rough pencil drawings to a scale of $1" = 4'$ showing each point where a loss would occur with a number corresponding to those used in the computations were made on $8\frac{1}{2}" \times 11"$ paper and serve the useful purpose of a visual picture for future reference and as an aid in the analysis of losses at strategic points where changes in area occur.

The actual flow characteristics determined from the preliminary studies for the various sections of the Pressure Aqueduct are illustrated below by a diagram (Fig. 1) converted into the head loss for a flow of one million gallons daily since that is a more convenient unit to use once the head losses have been determined.

The combined k_f for the Twin Intake section is calculated from Equations 5 and 6, and found to be approximately $k_f = .0000007$.

PRESSURE AQUEDUCT HYDRAULICS

Q = 400 c.f.s.

Point	Area (sq. ft.)	Quantity (c.f.s.)	Velocity (f.p.s.)	$\frac{V^2}{2g}$ (ft.)	Hydraulic Radius	Friction loss (ft./1000)			Value used	For "n" equal to	Length (ft.)	Estimated friction loss (ft.)	Elevation of Energy Gradient	Remarks
						Manning	Kutter	Scobey						
9	122.6	400	3.26	0.165	3.12	0.14	0.15	0.13	0.14	.012	9,587.79	1.3423		Precast Pipe
13	122.6	400	3.26	0.165	3.12									15% l.r.v.h.
14	154.0	400	2.93	0.060	3.31	0.11	0.11	0.10	0.11	.012	8.2	.010		
16	154	400	2.60	0.105	3.50	0.08	0.08	0.07	0.08	.012	25.0	.002		
17	154	400	2.60	0.105	3.50							.053		Bend
18	154	400	2.60	0.105	3.50	0.11	0.10	0.10	0.10	.013	142.0	.0142		Shaft
19	154	400	2.60	0.105	3.50							.053		Bend
20	154	400	2.60	0.105	3.50	0.11	0.10	0.10	0.10	.013	15,069	1.5069		Tunnel
21	83.8	400	4.77	0.353	2.59							.092		Bend
22	83.8	400	4.77	0.353	2.59	0.45	0.48	0.45	0.45	.013	53.8	.0242		Shaft
23	70.9	400	5.64	0.495	2.37	0.58	0.60	—	0.60	.013	4.0	.0024		
24	70.9	400	5.64	0.495	2.37	0.75	0.72	0.75	0.75	.013	12.12	.0091		

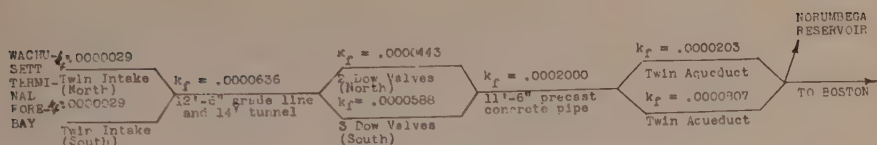


FIG. 1.—COMPUTED FLOW CHARACTERISTICS.

The combined k_f for the Dow Valve section is also calculated from the same equations, and is found to be $k_f = .0000127$; and, similarly, the combined k_f for the Twin Aqueduct section is found to be $k_f = .0000090$; and the estimated k_f for the entire line from the Wachusett Terminal Forebay to Norumbega Reservoir, for combined flow through all branches is the sum of the individual values or $k_f = .0002860$.

METHOD OF ESTIMATING MINOR LOSSES

It is not the purpose of this paper to take up the economic considerations which went into the building of the Pressure Aqueduct. The writer does feel, however, that the time spent by the designer in a careful study of the effect of what might be considered "minor losses", some of which might otherwise be neglected, is time well spent and may well result in savings entirely out of proportion to cost. In this connection, it is well to bear in mind the fundamental criterion, "will the conduit deliver the most water, consistent with future demand, for the least amount of money consistent with the life requirements?" In other words, what availeth it to design a pipe line of large diameter with a haphazard study of so-called minor losses, if a careful consideration of these losses and good design of transitions, larger size valves, etc. might have permitted the use of a smaller sized pipe which would have carried the same amount of water with great over-all economy? In this connection, it is well to bear in mind that the larger the diameter of the pipe, the less head which can be gained by increasing the diameter and the more "valuable" a consideration of so-called minor losses becomes.

All minor losses in the preliminary studies were based on some coefficient times the average velocity head between two points, or the difference in the velocity head going from the first to the second point, as the case might be.

There are two smooth right angle bends at the top and bottom

of the downtake shaft of the Southborough Tunnel constructed on a radius, at the center line, of 10' which give a value of $\frac{R}{D} = 0.71$.

The loss in head at each of these points was estimated to be about

$$h = 0.5 \frac{V^2}{2g}, \text{ where } V \text{ is the average velocity for the bend.}$$

The vertical and horizontal curves of the 11'-6" precast concrete pipe were all laid with a radius of 200' at the center line with a total curvature, throughout the length of 57,251 feet, of 1220° and the loss in head was estimated to be about

$$h = 0.25 \frac{V^2}{2g} \sqrt{\frac{\Delta}{90^\circ}}$$

where $\Delta = 1220^\circ$ and $V =$ the velocity in the main line.

In transition sections where there was an increase in velocity, the head loss was taken as $h = 0.10 \frac{V_2^2 - V_1^2}{2g}$, in which V_2 represents

the increased velocity, and, in transitions where there was a decrease in velocity, the head loss was obtained from Andres equation

$$h = f \frac{V_1^2 - V_2^2}{2g}, \text{ in which } V_2 \text{ is the decreased velocity, and } f \text{ an}$$

empirical coefficient depending on Θ which is double the angle between the axis of the pipe and its side, and may be obtained from King's Handbook of Hydraulics.

Losses through the 72" Dow Valves in the control section at the Shaft 4 Headhouse were estimated on the basis of $h = 0.24 \frac{V^2}{2g}$ in

which V is taken at a point which has an area about 80% of the area of the pipe section in which the valves are placed.

DETERMINATION OF THE FLOW CHARACTERISTIC OF THE PRESSURE AQUEDUCT FROM TEST RUNS

Test runs were made on the Pressure Aqueduct on three separate occasions from which determinations could be made of the flow characteristic of the Pressure Aqueduct as a unit from the Wachusett Terminal Forebay to Norumbega Reservoir.

From these tests it is also possible to demonstrate the reasonableness of the assumption of a coefficient of roughness " n " of .012 for the main section of 57,250 feet of 11'-6" precast concrete pipe. A more exact determination of this coefficient will be obtained at a later date, from piezometer connections which were placed at strategic points in the Head House at Shaft 4. From this data all the losses in the various sections will be ascertained.

For the first test, of October 28, 1940, the stop logs were removed from the southerly side of the intake works down to Elev. 272.80, allowing the flow to enter the aqueduct over the logs through this side. The energy gradient, downstream from the stop logs at the point where the 12'-6" grade line conduit begins, was determined to be at Elev. 274.45, which was obtained from the elevation of the slack water in the northerly side of the intake works to which 0.1' was added for estimated recovery of velocity head in the 12'-6" pipe which recovery was indicated by eddy currents in the slack water. The average water surface, over the period of the run, measured in the gate house at Norumbega Reservoir, was at Elev. 268.01 and the energy gradient at this point was about at Elev. 268.03. The over-all average loss of head, therefore, was 6.42'.

The average quantity flowing in the aqueduct during the period of 1½ hours, which was representative of the above average head loss, was estimated from the rise in level of Norumbega Reservoir from Elev. 264.60 to Elev. 265.50, which represents a gain in storage of about 9.5 million gallons, or an average flow of 152 m.g.d.

The over-all flow characteristic of the aqueduct from the test of October 28, 1940, determined from Equation 1 was, therefore, $k_f = .000278$ which checks very well with the estimated $k_f = .0002853$ for the corresponding sections leaving out the Twin Intake Section.

A second test run was made on March 6, 1941, in which the flow was all through the southerly set of 3 Dow valves and the head loss was estimated to be 3.5 feet from the water surface at Elev. 276.9 measured in the 1st manhole about 1,235 feet downstream from the intake at the Wachusett Terminal Chamber, and the water surface in the Norumbega Gate House at Elev. 273.4; for a quantity flowing in the aqueduct of 105 m.g.d. from a simultaneous spot reading of the venturi meter recorder at Shaft 4 Head House. This gives a value of $k_f = .000318$ for this condition which should be adjusted slightly

to about $k_f = .000321$ to allow for the length of aqueduct back to the Intake, in order to make a direct comparison with the other test runs. This k_f compares favorably with the estimated $k_f = .0003314$ obtained from Fig. 1 for the same conditions.

Using the adjusted value of $k_f = .0000124$ for flow through both sections of Dow valves, which is later determined in Table 4, we can determine the adjusted value of $k_f = .0000574$ for flow through the southerly Dow valves, only, as in this test; and by subtracting this value from the $k_f = .000321$ determined from the test and adding in the value of $k_f = .0000124$ as noted above for flow through both sections, we obtain the value of $k_f = .000276$ for the overall flow characteristic leaving out the Twin Intake Section which is in very close agreement with the test run of October 28, 1940.

A third test run was made on March 31, 1941, in which the flow was through both sets of Dow valves with a resulting estimated average head loss of 2.65 for a flow of 98 m.g.d. The quantity was estimated from the Venturi meter recorder totalizer for a 25-minute period during the run. For this test run $k_f = .000277$, which checks very closely with the result obtained from the runs of October 28, 1940 and of March 6, 1941.

Adding the average value of $k_f = .000277$, from the above three tests, to the estimated value of $k_f = .0000007$ for the Twin Intake Section, there is obtained a combined k_f for the Pressure Aqueduct from the Wachusett Terminal Forebay to the Norumbega Reservoir Gate House, of $k_f = .0002777$.

APPROXIMATE DETERMINATION OF THE COEFFICIENT OF ROUGHNESS OF THE 11'-6" PRECAST CONCRETE PIPE FROM TESTS

It has been pointed out that a very good determination of " n " for the 11'-6" line will be made at a future date, but it is possible to obtain a reasonable approximation from the test results.

Assuming that the difference, or error, between the calculated loss for all sections combined and the actual total loss, from tests, which can be represented in each case by k_f , may be absorbed by each section in direct proportion to the estimated k_f for that section; and a new k_f for each section thus determined.

Solving for the total head loss in the line, for the average quantity flowing in each of the tests, for values of n in the 11'-6" pipe of .011,

TABLE 4

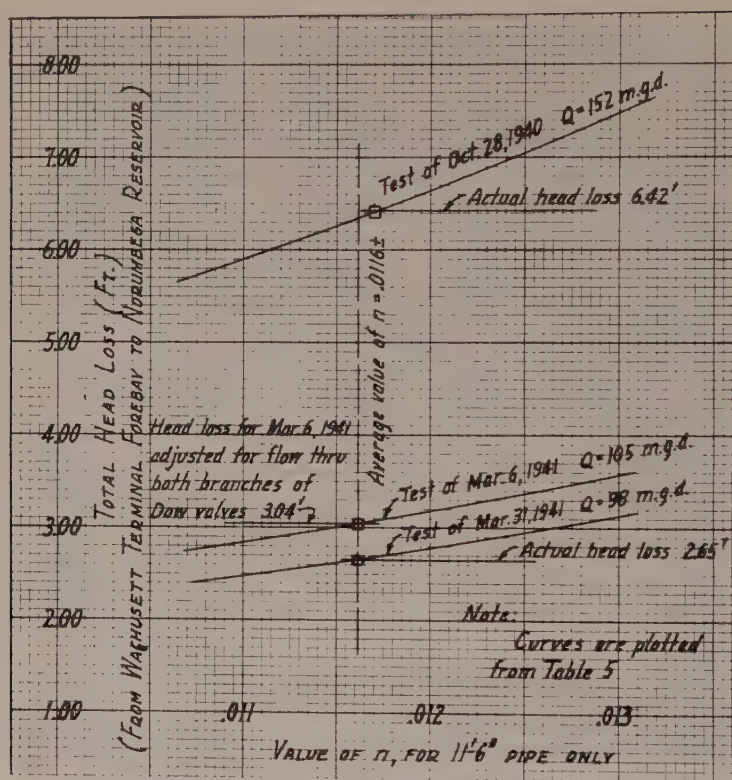
Section	Estimated k_f	Adjusted k_f
12'-6" pipe and 14' tunnel	.0000636	.0000620
Dow valves (flow through both branches)	.0000127	.0000124
11'-6" Precast concrete pipe	.0002000	.0001948
Twin Aqueduct Section	.0000090	.0000088
Total k_f , from estimate	.0002853	.0002780 from tests

.012 and .013, obtaining the head loss for that section by use of the Manning formula and using the adjusted values of k_f for the other sections, the following result is obtained, with the precision of slide rule computation:

TABLE 5

For test of Quantity flowing Actual Head Loss	Nov. 28, 1940 152 m.g.d. 6.42 ft.			Mar. 6, 1941 105 m.g.d. 3.5 ft.			Mar. 31, 1941 98 m.g.d. 2.65 ft.		
	Assumed value of n for 11'-6" pipe								
Section	.011	.012	.013	.011	.012	.013	.011	.012	.013
12'-6" pipe and 14' dia. tunnel	1.43	1.43	1.43	.68	.68	.68	.60	.60	.60
Dow valves (flow through both branches)	.29	.29	.29	.14	.14	.14	.12	.12	.12
11'-6" Precast concrete pipe	3.92	4.65	5.48	1.87	2.22	2.61	1.63	1.94	2.28
Bends in 11'-6" pipe	.07	.07	.07	.04	.04	.04	.03	.03	.03
Twin Aqueduct	.20	.20	.20	.10	.10	.10	.09	.09	.09
Total Lost Head	5.91	6.64	7.47	2.83	3.18	3.57	2.47	2.78	3.12

Plotting the results obtained from Table 5 as curves on Fig. 2, using n as the abscissa and head loss as the ordinate, indicates, from the points where the actual head losses cut the curves, if the original assumption and the head loss in bends is reasonable, that, for the 11'-6" precast concrete pipe with extremely smooth jointing, the value of $n = .0116$ is approximately correct, which corresponds to a Hazen and Williams coefficient of approximately $C = 146$.

FIG. 2.—VALUE OF n FOR 11'-6" PIPE ONLY.

CONCLUSION

It is the writer's opinion that the use of the foregoing method greatly simplifies the computations necessary in figuring flow networks for distribution systems and is a very useful tool in conjunction with the Hardy Cross method for adjusting the flow in these networks; the computer thereby being enabled to forget all formulae and all factors which influence loss of head once he has determined the flow characteristic or friction characteristic for any one assumed quantity flowing. Computations for head loss where the exponent of Q is assumed to be 2, may be readily made for any Q , from one setting of the slide rule, and for any other value of the exponent a simple alignment chart may be constructed from Equation 2.

The writer wishes to state that so far as his knowledge goes, the idea of using what he has called a flow characteristic, originated with Karl R. Kennison, Chief Engineer of the Metropolitan District Water Supply Commission, who has for many years used this general method in making hydraulic computations for flow in distribution systems.

RECORD TIME CONSTRUCTION AT QUONSET NAVAL AIR STATION

BY RAYMOND V. MILLER*

(Presented at a joint meeting of the Boston Society of Civil Engineers and Northeastern Section, American Society of Civil Engineers held on October 15, 1941.)

I AM honored in being asked to talk before a meeting of such a distinguished group of New England engineers as is represented in the two societies sponsoring this gathering. It was my privilege to meet a number of you at Quonset Point last Spring when you inspected the work in progress at our new Air Station. It is a distinct pleasure to renew that acquaintance tonight.

Those of your membership who came to Quonset seemed to be impressed with the magnitude of the project as well as the wide variety of construction operations being carried on.

We who are associated with the Quonset job realize full well that seldom are engineers and construction men privileged to work on a new clean-cut project combining such size and speed. I shall endeavor to sketch a few of the more unusual phases of this work.

The Naval Air Station at Quonset Point, Rhode Island, developed into one of the largest national defense jobs in the country. Every conceivable type of construction was encountered, and scarcely an operation was slowed down by the five months of winter weather that complicated operations almost immediately after the start of the project. From necessity, numerous construction procedures were developed that may prove useful elsewhere, and some of these will be given consideration in turn.

This extensive construction program involves the total expenditure of about \$39,000,000 to complete the project and includes the original allocation of \$1,000,000 for land.

When the first million dollars were released for construction purposes in November, 1939, the objective was to build a seaplane hangar,

*Commander (Civil Engineer Corps) United States Navy. Officer in Charge of Construction, Quonset Naval Air Station, Quonset Point, R. I. Member, American Society of Civil Engineers.

warming-up aprons and a ramp for the seaplanes of the Neutrality Patrol, together with living quarters for officers and men, and a dispensary. The work was awarded under a lump sum contract and attained usable completion in June, 1940. Those facilities are now just minor items on a site the size of the New York Worlds Fair that is dotted with many major construction projects, all accomplished under a single negotiated cost-plus-a-fixed-fee contract with full time naval supervision.

This form of contract was developed by the Bureau of Yards and Docks Navy Department, of which Admiral Ben Moreell, Corps of Civil Engineers, USN, is the Chief. It puts the contractors' organization and the navy management into a partnership, and has made possible the expeditious completion by the Navy of many important projects throughout the national defense establishment.

Under this setup the Bureau of Yards and Docks, by decentralizing and granting broad authority and responsibility to field officers, has avoided many possible delays. Decisions can be made promptly by local Officers-in-Charge. Purchases of material and equipment, as well as rates of pay of all personnel, are approved by the local naval organization. The cost of the work at the site is reimbursed each week to the contractors who receive a fixed sum for the services of their organization.

The operations at Quonset attracted considerable interest, and although naval restrictions must necessarily curtail what can be released about such a national defense project, many newspaper items and a number of technical articles concerning the work have been published.

QUONSET POINT (General-Geographical)

Quonset Point is a Cape on the west shore of Narragansett Bay. Providence lies twenty miles up the Bay to the north, and Newport, where the Navy has a War College, a Training Station and other important facilities, is 10 miles down the Bay. The New Jamestown Bridge to Conanicut Island is located a few miles south on the westerly side of the Bay.

The Naval Air Station at Quonset Point will be a principal center for the operation and repair of naval aircraft in this part of the United States. The appropriations have converted 800 acres of scrub-laden

land, 360 reclaimed acres of bay and swamps, and 70 acres on Hope Island off-shore, into an Air Station that will be second to none. A brief description of this project will serve as a background for the discussion of the construction activities that follows.

The land purchased for the Quonset Point Naval Air Station was roughly in the form of a right triangle with both its base (running east and west) and its hypotenuse (running northwest-southeast) bordering on the Bay. To bring it to a square about $1\frac{1}{2}$ miles on a side, the northeast corner was reclaimed from the Bay by dredging.

The dredging job involved over 21,000,000 cu. yds. of material. Some of the largest equipment in the country was used, and included four hydraulic dredges and one dipper dredge. Nearly 12,000,000 yds. of the hydraulic fill went into made-land for runways, two-thirds of this quantity being pumped between August and Christmas. The depth of fill forming the runway site was 25 ft. at the outer point. The material was pumped in behind a steel sheet pile bulkhead 11,000 feet long which was installed entirely with marine equipment. Some 9,000,000 yds. of additional dredging were required to provide a 35 ft. depth in a ship turning basin 3,000 ft. square and in approach channels from the deep waters of the bay. Earth excavation amounted to over 3,000,000 cu. yds. plus some additional rock work.

A view from the control tower of the operations building reveals an interesting panorama of the varied types of construction required at the Station. From this point may be seen landplane hangars and parking areas; the large expanse of filled area on which has been constructed landplane runways; the seaplane hangars; concrete ramps and parking aprons for seaplanes; a carrier pier extending out into the bay; power and sewage disposal plants; the industrial area, including aircraft storehouse, general storehouse, miscellaneous maintenance buildings, and an enormous assembly and repair shop building; the personnel buildings consisting of barracks, mess halls, administration, dispensary, enlisted men's and officers' recreation buildings, cafeteria, cold-storage, commissary and laundry buildings, and a defense housing project; a colony of homes for officers and married enlisted men; a network of roads; and a railroad connection paralleled by a main access road leading to the Station.

The history of the construction of these many features that comprise the Air Station is a record of expedited construction under gen-

erally adverse conditions. Work began under the cost plus fixed-fee contract on July 16, 1940. The contractors are the George A. Fuller Company and Merritt-Chapman and Scott Corporation. These two well-known firms operate jointly as a single unit. The results attained speak for themselves and reflect great credit on the resources and organizing ability of both companies.

For the most part the basic construction work was undertaken and largely completed through about five months of winter weather so that the Station could be placed in operation at the earliest possible date. On December 17 the first landplane alighted on a runway that was formerly Narragansett Bay.

At the beginning of construction, only incomplete plans had been prepared. In fact, in the case of all the industrial structures, a full set of plans was not available until completion of the buildings. Partial plans were submitted to steel companies for bids—upon a pound basis—on steel reinforcing and rolled sections. Fabrication was carried on as plans were finished. Layouts for plumbing, lighting and other facilities were completed as the buildings went up.

Excavations and foundation work were initiated on units for which the delivery of structural steel and other building materials was assured. Early closing of these buildings permitted interior work to be carried on successfully through the winter months.

Plans for similar buildings erected at other bases were used in part. The general storehouse, for example, is patterned after a structure at Kodiak, Alaska, but more bays were added, foundations changed, etc. Other utility buildings were similarly re-designed in the drafting rooms at Quonset. Plans for the \$1,000,000 bulkhead, new pier, roads, runways, power plant and various other units were prepared locally in their entirety.

Considerable study was required in the planning and coordinating of operations so that construction equipment could be successfully transferred from one project to another without serious delay or hold-up. Construction priority was given those buildings vitally needed for the storage of materials and naval operation equipment, in accordance with the general plan of obtaining a usable base at the earliest possible date.

The cost-plus-a-fixed-fee form of contract was the only type that could bring the quick results desired without complete plans. The time

required in advance of construction to prepare plans and specifications comprehensive enough for bidders to use in arriving at estimates and bids was thus saved. It is possible to initiate new projects promptly and push work energetically with only a general outline of the work to be done. Changes in requirements are met without the delay and paper work incident to supplemental agreements or change orders required under the competitive bidding form of contract.

In conformity with the Bureau's policy of utilizing the services of outside engineers wherever they could be employed to advantage, Gibbs and Hill, Incorporated of New York City were engaged to design the power plant, the distributing systems, the laundry, and cold storage buildings, and to modify as necessary the design of the assembly and repair shop. This firm performed most of its work in a design office located on the site.

The administration building, cafeteria, dispensary, landplane hangars, barracks, quarters and recreation facilities for officers and enlisted men, as well as the Gatehouse and fence, were designed by Albert Kahn, Associated Architects and Engineers, Detroit, under the direction of the Bureau of Yards and Docks.

HIGHWAY AND RAILROAD CONSTRUCTION ON PEAT

For an establishment as large as Quonset both rail and highway access are of course necessary, and the construction of these facilities was attended by some of the most interesting operations on the project.

Railhead is located at Davisville about three miles west of the Reservation on the New Haven railroad, and the rail connection to the Station is on tangent for virtually the entire distance. The new access highway, 36 ft. wide with 7 ft. shoulders, parallels the railroad for the first $1\frac{1}{2}$ miles from the Station. It then swings wide to provide space for a cloverleaf intersection with the Boston Post Road which has been carried over both rail and highway lines on concrete rigid frame bridges. The Post Road marks not only the halfway point between the Air Station and the railhead, but it is the dividing line between two completely different topographies. To the west the railroad right-of-way passes through deep rock cut. To the east both highway and railroad run through swamp land and peat bogs which required deep fill. Except for the extreme care required in blasting the locally famous "Devil's Foot Rock", which rose to a height of

20 feet immediately adjacent to the Post Road, the rock work was not unusual. Difficulties were met, however, in placing fill 70 ft. wide and up to 30 ft. in height over the peat.

Three principal peat deposits were encountered. One was 900 ft. long and 25 ft. deep; the other two were each about 500 ft. long and 8 to 10 ft. deep. Based on careful cost estimates and some preliminary experimentation it was decided to blast the deep deposit and excavate the two shallow ones.

In removing the peat by blasting, a section of fill about 100 ft. long and some 20 ft. high was first built out over the peat. The pipes were then driven through this fill into the peat and loaded with dynamite which was subsequently detonated. The heavy surcharge of fill confined the energy of the explosion and caused the peat to be pushed out beyond the edge of the fill. The fill then settled into the depression formed.

Because of the difficulty experienced in driving pipes through the fill a change of procedure was inaugurated after the first attempt, and thereafter they were driven into the peat ahead of the fill. Although filling operations displaced some of the pipes, this procedure proved more economical and equally satisfactory.

For the shallower peat deposits, draglines cast the peat beyond the limits of the fill area. In this operation fill was placed at the edge of the peat bog, thus providing a firm foundation from which to work. As fast as the peat was cast aside, more fill was added which in turn pushed the remaining peat ahead of it.

As a result of the varying depths of peat involved, fair comparisons between the two methods are difficult to obtain. Dragline excavation and sidecasting were favored for two reasons. In the first place, the heavy mat of decayed vegetable matter and tree roots on top of the peat had to be broken up before the fill could be placed for blasting, otherwise the fill would be held in suspension and thereby lose its effectiveness as a surcharge in displacing the underlying strata of peat. The work required in breaking up this mat was a separate and extra operation with the fill-and-blast procedure, while it was an integral part of the dragline-excavation method. Secondly, the dragline excavation removed all of the peat, while blasting did not effect complete removal with the size of charges used. The railroad embankment was cambered some 5 in. over the peat areas and is still above grade.

RUNWAYS IN A HURRY

The paving at Quonset covers an area equivalent to 100 miles of road 20 feet wide. Most of the runway pavement installation followed almost immediately on recently placed hydraulic fill, a situation which resulted in an unusual construction operation. The original plan had been to let the fill settle and drain during the winter months and to start paving operations as soon as the frost was out in the Spring. Other considerations ruled out any such delay, however, and engineering planning had to give way to construction expediency.

A surface on the frozen fill that could be graded and rolled into a pavement sub-base was the first problem. This was solved by placing a 3 or 4 in. layer of dry material rich in clay binder which was spread by blade graders and compacted with tandem rollers. On days when the sun thawed the surface of the hydraulic fill into mud, gravel was placed ahead of the clay to take up the water. On this latter surface the pavement was then laid. To prevent heaving of the sub-grade due to thawing action, placement of asphalt followed immediately the fine grading and rolling. The only other precaution necessary was to lay the paving hotter than normal: namely, at 350 to 375 degrees and to cover the hauling trucks with tarpaulins to reduce the heat loss in transit from the 20 degrees permitted by the specifications to only 5 degrees. The maximum haul from the mixing plant was about 1 mile.

Operations were carried on by three shifts a day in all kinds of weather except rain, and in air temperatures varying from 10 to 40 degrees. The arrival of warm weather revealed no settlement of consequence.

The winter work furnished experience in job organization and construction technique which proved valuable in laying the rest of the runways. Pavement was laid in strips 10 ft wide and 800 to 900 ft. long, the maximum length that would still permit a hot bond with the next adjacent strip. Cold joints had to be painted with hot asphalt before the next strip could be laid.

VARIABLE PILE PENETRATION

One of the early problems of construction was encountered on the foundation for the general storehouse, a three-story reinforced concrete structure designed for live loads of 500, 300, and 250 lbs.

per sq. ft. respectively, on the 1st, 2nd and 3rd floors. Despite a relatively large number of borings, subsurface conditions were not as expected and pile penetration varied greatly even in the same 11 ft. square footing. Since footings were on 20 ft. centers and each contained 13 piles, the number of pile cut-offs was extremely large and lengths were quite different. Fluted tapered steel shells filled with concrete designed for 30 tons each were used. Despite the taper it was found possible to use the shell cut-offs for lengthening piles that proved too short; or, in combination with new bottom-boot sections, to weld the various length cut-offs into new piles.

VACUUM CONCRETE

To speed up setting time and form removal, extensive use was made of vacuum mats on the concrete floor slabs in the barracks, landplane hangars, storehouse, operations and administration buildings. Most of this concreting was done in winter weather when heating was required, hence speeding up the time of set by removing excess water resulted in a substantial economy. Procedure in the landplane hangars, for example, was to apply the vacuum mats to the slab surface for about 20 minutes immediately after screeding. The mats were then removed and the slabs covered with burlap, 6 inches of hay, and a top covering of burlap. Under this protection the concrete surface temperatures never dropped below 30 degrees even when the air temperature hovered around zero.

Another important use of vacuum concrete was in a casting yard where slab covers for the miles of utility trenches were made. Here the speed-up possible with the mats permitted 150 of these 3×4 ft. slabs to be poured and removed from the forms in an 8-hour shift.

REINFORCED CONCRETE CARRIER PIER

A major structure at the Naval Air Station is a pier extending out into the bay where deep draft ships, including aircraft carriers, can berth. Its supports are steel H-piles, and the design called for encasing the tops of these piles in concrete down to 3 ft. below low water. Pile-driving was completed early in February and to avoid delay in starting work on the concrete deck slab, the pile encasement had to be done in winter weather. Special protection, therefore, was necessary.

Forms for the encasement consisted of corrugated metal shells. They were supported by two short pieces of railroad rail inserted through holes on opposite sides of the shells just above the high water line and welded to the flanges of the piles. The rails projected about a foot outside the shells and were installed with the wide bottom flange up. They later served as supports for the deck forms. Another function of the rails was to act as shear dowels for the concrete encasement, a service in which they are complementary to steel angles welded to the webs of piles.

Concrete was mixed in a floating plant having heaters in the mixers, and conveyed to the forms in chutes. High-early-strength cement was used and, as a final precaution, metal drums were lowered over the encasement and fed steam for 72 hours. By maintaining a temperature of 70 deg. for this period the concrete attained a strength of 3900 lbs. per sq. in., as measured by test cylinders broken after 48 hours. The period of steam curing was progressively shortened as outside air temperatures rose with the approach of Spring.

ERECTING 160 FT. SPAN TRUSSES AT THE A. & R. SHOP

The largest building at Quonset is the assembly and repair shop. This building is notable for its diverse types of framing, ranging from simple beam-and-girder bays to the 160 ft. trusses that span the main assembly aisle. The erection of these trusses, of which there are some two dozen, was accomplished without the use of falsework by assembling them on the ground and lifting them into place with three crawler cranes. Each truss weighs 27 tons, and since their bottom chords are 45 ft. above the floor, the erection operations were spectacular although, as it worked out, relatively simple.

HANDLING SALAMANDERS SAFELY

Barracks, administration building and bachelor officers' quarters at Quonset have concrete floors and brick veneer walls. All had to be constructed during winter weather. The usual tarpaulin enclosure and salamander heating was resorted to, but details of the layout were somewhat unusual and very effective.

As soon as the two-story steel frames were erected, they were surrounded by scaffolding for the brick masons and enclosed in tarpaulins. At the same time the permanent roof was put on giving

complete protection from the icy winds. The salamander heaters were then installed, and for safety and convenience, were suspended from the second floor beams in wood cradles. The salamanders were so braced they could not tip over. The bottoms of the salamanders were about 3 ft. above the first floor, a height that placed them out of the way of the workmen and was at the same time convenient for firing.

Spaced on about 10 ft. centers, both ways, the salamanders effectively heated the entire building so that concrete floor slabs could be safely placed. Also, enough heat escaped through wall and door openings to permit masons to lay up the brick walls without having salamanders on the scaffold with them.

HOMES FOR STATION PERSONNEL

In a Naval establishment of this calibre, living quarters have to be provided for the administrative and operating personnel. This part of the construction program was as unique and interesting in its way as were the more formal engineering problems involved in the development of the operating section of the Station.

Previous to the start of construction operations, summer colonies were thriving at Quonset Point, Willow Point and Fry's Cove along the south and west boundaries of Quonset bordering on Narragansett Bay. One of the first projects was to appraise these shore cottages for possible rehabilitation and relocation in the permanent residential development.

A few of the summer cottages were of such flimsy construction they could not readily be used elsewhere and promised to be of little salvage value. Some of these were broken up by simply running a bull dozer through the walls. A total of 275 houses were taken over, some at the season's peak. Occupants were permitted to remain as long as possible and few complaints were registered. A committee of five appointed by the cottagers conferred with the Navy personnel and aided in maintaining generally good feeling. Incidentally, a total of 110 bodies was removed from six cemeteries on the site.

Briefly, there were three distinct uses for these houses: (1) Officers' homes, (2) married enlisted men's quarters, and (3) defense housing for operating personnel. Twenty were selected for Officers' homes; twenty were allocated for married enlisted men; and the balance of the usable cottages was set aside for incorporation in the 238-unit housing development for Station personnel.

Each house to be remodeled was given a number. Field measurements were taken; complete floor plans and elevations were drawn; and architectural studies were made to determine the nature and extent of necessary interior and exterior alterations. While the office work was in process, each cottage was braced and placed on timber skids, dragged by tractors to the predetermined location, and jacked into position on a prepared foundation. Remodelling operations followed and included changes in heating, lighting and plumbing facilities. Today these housing groups are places of distinctive beauty on the Station.

Practically all of the relocated houses had to be placed in treeless areas. The land acquired for defense housing immediately adjacent to the Air Station contained many fine trees, and a large number were uprooted, bagged, hauled and replanted in the vicinity of the personnel buildings. Ordinarily the cost of such a procedure would have been prohibitive, but in this case the heavy equipment brought on the work for other operations was utilized for moving trees at small expense. Extensive green lawns have also been planted and these together with the transplanted trees have already changed the vast wasteland into an attractive reservation.

The construction operations described have provided subject matter for several articles in *Engineering News-Record*. Coverage of some material in this paper follows directly that given in the treatise, "Special Construction at Quonset," published in the June 5, 1941 issue of *Engineering News-Record*.

PERSONNEL

At the peak of construction, expenditures ran as high as \$1,100,000 per week and averaged between \$800,000 and \$900,000 per week. Nine of the weekly reimbursement vouchers were in excess of \$1,000,000 each. The largest weekly payroll for the construction and administrative force was \$554,000. A maximum of 11,724 people were employed at the site.

For security purposes, these people were all finger printed and photographed. The problem of handling such a large group was solved by installing a fingerprinting and photographic laboratory in a large bus formerly operated at the World's Fair. This mobile laboratory traveled about the job accomplishing its purpose. A total of over

24,161 sets of finger prints and photographs were taken for the files and uncovered a surprising number of police records. Fortunately, most of these were not serious.

The number of technical and administrative employees was necessarily large in view of the tremendous scope of the project and the high speed at which it was carried out. This force totalled more than 1000 men and included project managers, inside and outside superintendents, engineers of all kinds, architects, draftsmen, estimators, surveyors, purchasing agents, expeditors, accountants, auditors, inspectors of materials and construction, time and material checkers, employment managers, insurance and claim agents, clerks, stenographers and other associated ratings. The salaries paid took into consideration the high tension and long hours involved, and were correspondingly higher than those paid under normal conditions. The coordination of so large a force hastily assembled from a variety of sources speaks well of the organizing abilities of all concerned.

A tremendous housing problem was raised by the flow of workmen to a project located in a rather sparsely settled section. When spare rooms ran out, some home owners lined up cots in their living rooms to accommodate three or four well-paying guests. Local school systems are still staggering under the impact of a vastly increased registration.

Despite the rush character of the project and large turnover of men, the accident rate has not been high. The usual number of minor accidents have occurred but only two deaths are recorded. Judged by the normal rough estimate of one death per \$1,000,000 spent on a construction job, the Quonset Point Air Station has been a good risk. Incidentally, other insurance claims presented cover a range from oyster beds to glass houses; from a faintly humorous to a tragic character. The many personal anecdotes and human nature stories which enlivened or complicated various phases of the work cannot be detailed here, but they prove that technical plans alone do not cover all features of such a large undertaking.

So much for what can be done in a year. Ordinarily there would be no reason for trying to cram a three years' job into a single year but these are not ordinary times. The Quonset Air Station, in my opinion, provides a fine example of what the construction industry of this country can produce in the way of speedy, permanent construction.

POST WAR HIGHWAY ECONOMICS

BY CHARLES M. UPHAM*

(Presented at a Joint Meeting of the Boston Society of Civil Engineers and the Highway Section, B.S.C.E., on November 26, 1941.)

EMPLOYMENT

UNDER normal conditions the total labor force in the United States amounts to about 40 per cent of the population. This means that 132,000,000 people, the current total population would be supported by about 53,000,000 workers. In 1932, a population of 125,000,000 was being supported by 37,000,000 which was only about 75 per cent of the total. It was conclusively proven that prosperity could not exist with one-quarter of the working population idle. The construction industry normally employs directly and indirectly 13,000,000 people. Averaging the years 1926-1933, the total annual construction expenditure was about \$9,000,000,000 of which private construction amounted to \$3,300,000,000, public utilities \$3,000,000,000, public highways \$1,375,000,000 and other public construction \$1,325,000,000. The highway program furnished employment for 1,400,000 annually and supported a total of 5,000,000 people.

NATIONAL INCOME-DEBT

The unprecedented growth of highway transport has overtaxed the highway facilities and is evidence that the highway construction program has never kept pace with the demand, leaving no doubt concerning the justification for a much larger expenditure for highways as soon as world conditions permit. The question of how much construction can be undertaken annually involves a study of its effect on the national economy.

With full employment it would be possible to have a national income in excess of \$100,000,000,000. This means that services and goods produced would amount to this figure, and it is assumed that with the full labor force working and the resulting high national in-

*Engineer-Director, American Road Builders' Association, International Building, Washington, D. C.

come, government receipts would more than balance expenditures. Under present conditions it is impossible to forecast either the length of the emergency or the ultimate world economic situation. It is estimated that within two years every available person will be working and at the present rate about one-half of the working force will be engaged either in defense production or in the military forces.

The problem to be solved after the war is the shifting of this defense employment to peacetime activity without reducing the national income and without reducing the employment. Government spending will continue on a huge scale until the emergency is over and along

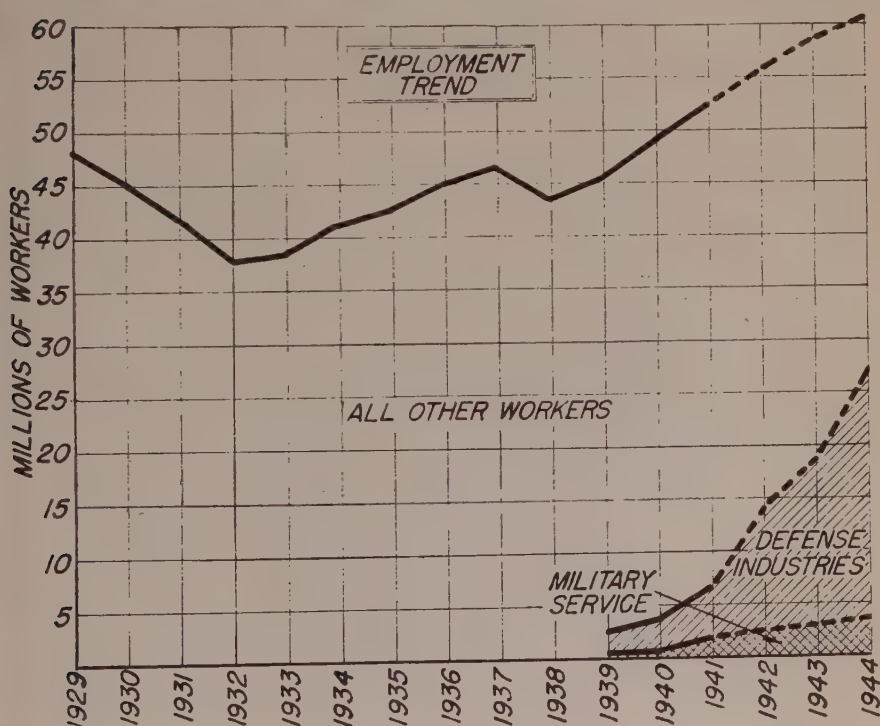


FIG. 1.—EMPLOYMENT TREND

By 1944 one-half the total labor force will be engaged either in defense work or in the military forces. When hostilities cease, the greater portion of the defense workers and military forces must be shifted to peacetime activity. A planned program of highway construction should be ready for the transition period, to provide for the employment of persons thrown out of work.

with it an increasing national debt. The question of financing a program of public works during the post war period involves a study of expenditures against receipts, interest rates and debt trend. With full employment and a high national income, government receipts would be increased to a point where they would more than balance expenditures, the debt would reach its maximum and remain static or be slightly reduced until the return of normal conditions. With industry functioning normally and with a slackening of government spending, the national debt could be further reduced.

Government expenditures for purely relief purposes do very little

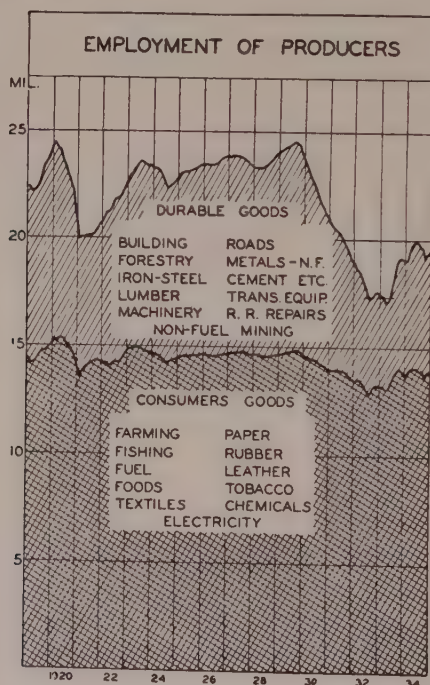


FIG. 2.—EMPLOYMENT OF PRODUCERS

The labor force of this country is normally divided equally into two groups, the consumers and producers. The latter group is divided into producers of durable goods and producers of consumer goods. In periods of depression the collapse occurs in the producers of durable goods. This group which includes the construction industry accounted for 75 per cent of the total unemployment during the last depression. The initiation of a well planned highway construction program at the start of a decline in unemployment would keep the durable goods producers active and avert a major decline.

for the economic structure. Projects undertaken must be chosen for durability, for the individual, and for general welfare and for future usefulness if they are to be effective. Highways are in this category and perhaps the greatest asset lies in the fact that a large improvement program can be quickly started and the improvements utilized immediately.

The development of highway transportation has become the nation's best investment. The improvement of highways and streets has not been adequate to meet the demand and while the employment-producing characteristics of construction operations outrank other types of construction, the secondary effects of the utility created are even more beneficial to the national economy.

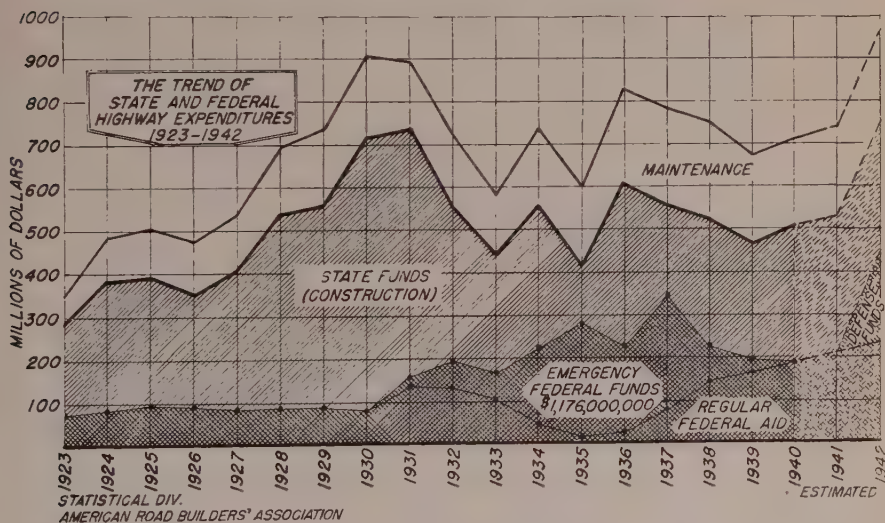


FIG. 3.—THE TREND OF STATE AND FEDERAL HIGHWAY EXPENDITURES, 1923-1941

During the reconstruction period following the last war, state and federal expenditures for highways increased from \$300,000,000 in 1923 to more than \$700,000,000 in 1930. Other construction followed this same trend. Even during the peak years of highway construction, the improvement did not meet the current demand and was entirely inadequate for the future, yet despite recent rapidly increasing vehicle registration and highway usage, the construction program has never reached the peaks of 1930 and 1931. As a durable goods producer the construction of highways is an important factor during a period of industrial stagnation, yet the demand for highways is greater during prosperous periods. Under any conditions there is economic justification for bigger annual programs than those of 1930 and 1931.

ECONOMIC BALANCE—IDLE MONEY

In a period of business depression in a country such as this, economic unsettlement occurs when production and consumption do not balance; inventories become excessive, unemployment increases and there is general retrenchment. Money becomes stagnant and piles up in the banks, a situation which would not occur if everything produced was consumed and if the entire income from the production of goods and services was reinvested.

If the total amount of idle funds could be put into useful construction during periods of stagnation, these funds which at times amount to 18 per cent of income, would eliminate unemployment and bring back a prosperous condition. Money must be kept working. It

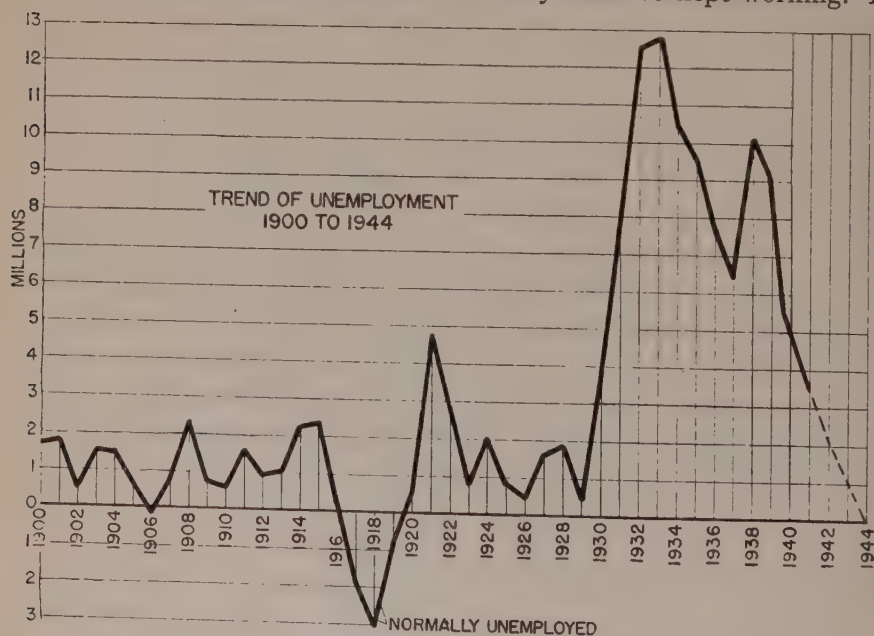


FIG. 4.—TREND OF UNEMPLOYMENT

Economists predict that defense activity will eliminate unemployment by 1944. A breakdown of the classes of unemployment during the thirties showed that 75 per cent occurred in the producers of durable goods which includes important items such as highways and bridges. The durable goods producers are busy currently, building ships, bombs, and other implements of war. This group must continue maximum activity after the war if full employment is to continue. The building of highways would be the logical major peacetime activity to keep production of durable goods at a high level.

is of little use lying idle, and if there is no demand for its use by private industry, it should be used on public works until such time as industry can take up the slack. During the twenties about \$10,000,000,000 in Liberty Bonds were liquidated. The funds could not be taken up by industry and eventually found their way into speculative markets which finally collapsed. Had these funds been placed in useful public works, such as highways, during this period, there would have been less money for speculation, and it is doubtful if the economic depression would have been as severe and the country would have profited by a much needed transportation system.

Following the last war, a short period of unsettlement was followed by ten years of increasing business activity. Road building was

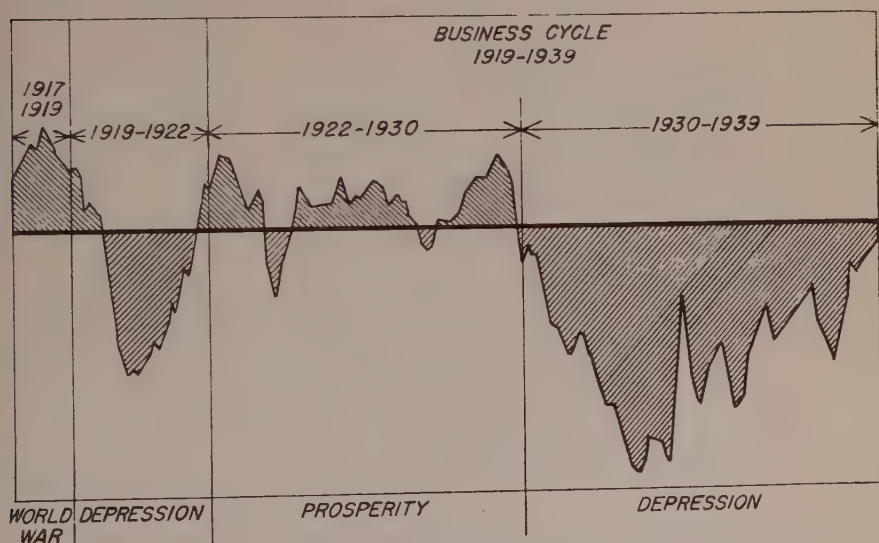


FIG. 5.—BUSINESS CYCLE

The last world war stimulated business similar to the present high industrial activity. This was followed by a short period of depression in which transition from war to peacetime industry took place. After this came a period of prosperous business conditions as the demands of peacetime requirements were being satisfied, and ended in the long depression of the thirties. A similar cycle has taken place in all modern wars in all countries. It is reasonable to assume that the present conflict will follow the same economic cycle. The remedy for the extreme fluctuations in industrial activity would be to stop them before they get well underway and out of control. Since the durable goods producers are always the group most seriously affected at the beginning of an employment downtrend, a public works program would act as a brake at the first sign of a depression following the war.

stimulated by an increase in automobile registration of 9,000,000 cars during the period, which was about twice the increase registered during the following decade. These were important factors during the reconstruction period. At the present time there is no industry in sight with the possible exception of aviation, comparable to the production of automobiles during the twenties, to take up the slack during the next transition period. Shortages in many commodities the world over will greatly exceed those which existed after the last war due to currently increasing restrictions on civilian requirements. It will take time to shift 27,000,000 men from defense work to the production of needed commodities. This is the critical period and the high national income level and full employment must be maintained. A planned post war highway program should be completed and ready to go when necessary.

HIGHWAY PROGRAM

The construction of highways is peculiarly suited to the purpose. It is doubtful if there is any area where highways have been overbuilt and there is no question about the need for additional facilities not only in the heavily-populated areas but also for the benefit of agriculture. The present highway program is shifting more and more to strictly defense construction. While a portion of this construction on the strategic network will be beneficial for peacetime needs, much of the access road construction could fall into disuse after the emergency is over. It is likely that the program will do little better than hold its own until the war is over, which will lead to an increased demand for replacement and new construction.

Fortunately, surveys which have been made in recent years by Public Roads Administration, state highway departments and other agencies give a clear picture of the location and volume of the needed future program. There is an urgent demand for the contemplated program. It has a definite place in the national economy, relieving unemployment and increasing the national income. However, regardless of unemployment and the general economic situation, there exists the necessity for a long-term highway program much larger than any hitherto put into effect.

During the years 1926-1933 the average annual public construction expenditure amounted to less than \$3,000,000,000, of which one-half was spent on highways. This was 17 per cent of the total public

and private construction expenditure. Private construction accounted for 83 per cent and was an important durable goods producer during the twenties, playing a big part in keeping employment at a high level during that period. Its collapse, however, played an equally important part in the economic nose dive of 1929.

Inasmuch as both private and public construction are durable goods producers and have a similar effect on the national economy, an increase in public construction during periods of declining private construction would reduce unemployment until normal conditions returned.

A \$2,000,000,000 annual highway program would be 22 per cent of the total annual average construction program of 1926-1933 and would average about \$600,000,000 more than was spent annually during that period. This would stabilize the employment of 2,000,000 persons annually in the durable goods industry and almost half as many more in the consumer industry. The annual expenditure could be increased during periods of business depression.

The volume of private construction fluctuates with business conditions. The volume of public construction can be more readily stabilized at a given level. From the standpoint of national economy an annual highway program of at least \$2,000,000,000 would be justified and would have the effect of stopping extreme fluctuations in business cycles.

HIGHWAY ECONOMICS

Highway construction and the benefits accruing to the general welfare as the result of highway transportation have proven their value in the national economic picture during the last thirty years. The demand for highways manifested itself from the beginning of the automobile era and the value of highway construction as a business stimulant and as a means of relieving unemployment was proven during the recent depression years.

Since 1932 various kinds of public construction have been put in effect for the purpose of assisting in the stimulation of business activity and putting people to work. Two government agencies have completed studies concerning these factors and both have proven the exceptional value of highway construction in meeting the requirements of both objectives.

The Bureau of Labor Statistics, Department of Labor, recently completed a five year study of the economic effects of various kinds of government construction projects. These included water supply, reclamation, residential and non-residential buildings, sewers and steam and electric power plant projects. It was found that highway and street construction provided the greatest amount of direct and indirect employment per dollar spent. Slightly less than half of the employment was at the job site and the remaining off-site employment was at the mills and quarries.

Exhaustive studies have been made by the National Resources Planning Board on the effects of various types of Public Works spending as it influences unemployment and other economic conditions.

As a result the Board has enumerated six considerations which must be fulfilled if the required benefits of a public works program are to result:

1. The utility of the work to the community.
2. The flexibility of the project, the ease with which it can be undertaken at the appropriate time, and the ease with which its prosecution can be controlled or curtailed in relation to the need for rapid expansion or contraction of employment.
3. The adjustment of the project to the character and regional distribution of unemployment.
4. The adjustment of the material requirements of the project to available industrial plant capacity.
5. The employment creating value of the project.
6. The extent to which the project induces further new investment and employment.

Funds spent in the improvement of highways fulfill all these requirements better than any other form of public works. The value of the highway as a utility is reflected in every phase of the Nation's welfare. The social, economic, industrial and agriculture life of the nation is dependent on highway transportation.

OF GENERAL INTEREST

PROCEEDINGS OF THE SOCIETY

MINUTES OF MEETINGS

Boston Society of Civil Engineers

OCTOBER 15, 1941.—A regular meeting of the Boston Society of Civil Engineers was held this evening at Eastman Hall, Massachusetts Institute of Technology and was called to order by President Albert Haertlein at 7:30 P.M. Two hundred twenty-five members and guests were present and 189 persons attended the dinner.

This meeting was the Annual Student Night with representatives from the Student Chapters of the American Society of Civil Engineers at Harvard University, Massachusetts Institute of Technology, Tufts, Rhode Island State College, University of New Hampshire, Brown University and of Northeastern University, which is also a Section of the Boston Society of Civil Engineers. This meeting was also a joint meeting with the Northeastern Section, American Society of Civil Engineers.

The President welcomed the 150 students who attended the meeting and expressed his appreciation of the cooperation of the student organizations and of the faculty members in making this meeting a success.

President Haertlein then introduced the speaker of the evening, Commander R. V. Miller (CEC) USN—Officer in

Charge of Construction, who gave a very interesting talk on "Record Time Construction at Quonset Naval Air Station, R. I."

The \$25,000,000 Naval Air Station at Quonset Point, Rhode Island, involves every conceivable type of construction. It is one of the largest national defense jobs in the country. The planning and execution of every phase of the work were carried out with greatest despatch, and not even winter conditions during the first five months were allowed to slow down the progress of each step in the development of this immense undertaking.

The talk was illustrated by photographs and motion pictures. The meeting adjourned at 9:00 P.M.

EVERETT N. HUTCHINS, *Secretary*.

NOVEMBER 26, 1941.—A regular meeting of the Boston Society of Civil Engineers was held this evening at the Engineers Club and was called to order by President Albert Haertlein. This was a Joint Meeting with the Highway Section, B. S. C. E. Sixty-eight persons attended the meeting and fifty-eight attended the supper.

President Haertlein announced the deaths of the following members:

T. T. HUNTER HARWOOD, who was elected a member March 20, 1889, and who died November 21, 1940.

CHARLES F. FITZ, who was elected a member May 20, 1896, and who died July 11, 1941.

The Secretary reported on the election of the following new members:

Grade of Member: Albert J. Colacey, Hugh P. Duffill, Frederick J. Fox, Arvo A. Nelson,* Darel O. Packard,* Albert E. Sanderson.

The President called upon Mr. Herman S. Swartz, Chairman of the Highway Section, who stated that there were no matters of business to be conducted by the members of the Highway Section. He expressed his appreciation of the opportunity for the Highway Section to join with the Main Society in this particular meeting which is of special interest to members of that section.

President Haertlein then introduced the speaker of the evening, Mr. Charles M. Upham, Engineer—Director of the American Association of Road Builders, who gave a very interesting talk on "Post War Highway Economics", illustrated by lantern slides. An interesting question period followed the talk.

The speaker was given a rising vote of thanks.

The meeting adjourned at 9:00 P.M.

EVERETT N. HUTCHINS, *Secretary*.

DECEMBER 17, 1941.—A regular meeting of the Boston Society of Civil Engineers was held this evening at the Engineers Club and was called to order by President Albert Haertlein. This was a Joint Meeting with the Sanitary Section, B. S. C. E. Fifty-four persons attended the meeting and forty-seven attended the supper.

President Haertlein announced that the January meeting of the Society will be held on January 14, 1942, instead of on the usual fourth Wednesday.

The President called upon Mr.

George W. Coffin, Chairman of the Sanitary Section, who stated that there were no matters of business to be conducted by the Sanitary Section.

Mr. Coffin took this opportunity to refer to the honor which has just been conferred upon President Haertlein, namely, his appointment by His Excellency, Governor Leverett Saltonstall, to the newly created Board of Registration of Professional Engineers and Land Surveyors, authorized by Chapter 643, Acts of 1941 (subsequently at the organization meeting of that Board, President Haertlein was elected Secretary of the Board).

President Haertlein then introduced the speaker of the evening, Mr. Roger W. Armstrong, Deputy Chief Engineer, Board of Water Supply of New York City, who gave an interesting talk on the "Delaware Water Supply System", illustrated by lantern slides.

The speaker was given a rising vote of thanks.

Meeting adjourned at 8:45 P.M.

EVERETT N. HUTCHINS, *Secretary*.

Sanitary Section

APRIL 2, 1941.—A regular meeting of the Sanitary Section was held this evening at Northeastern University, attended by 22 members and guests, preceded by a supper at Child's Old France Restaurant attended by 16 persons.

The meeting was called to order at 7:00 P.M. by the Chairman, George W. Coffin. He outlined the plans for the Spring Outing to Cranston and Quonset, R. I.

The Chairman introduced the speaker of the evening, Mr. George G. Bogren, Sanitary Engineer, Weston & Sampson, Boston, who spoke on "Grease Recovery from Industrial Wastes."

Mr. Bogren presented a very fine treatise, which he limited to the recovery of grease from wool-scouring wastes. He discussed the principal methods of wool-scouring, which are: (1) Scouring in an

aqueous solution, (2) Scouring with organic solvents, and (3) The "frost-wool" process. Since the last two processes are not widely used, the speaker elaborated only on the first method.

The paper was discussed by Prof. Edward W. Moore of Harvard Graduate School of Engineering and by Mr. Stuart E. Coburn of Metcalf & Eddy. The former described an extraction process developed in England in 1939, and the latter brought out the possibility of grease recovery from sewage.

The meeting adjourned at 9:25 P.M.

WALTER E. MERRILL, *Clerk*.

MAY 17, 1941.—Excursion.—On this date the Sanitary Section sponsored a trip to the new sewage treatment works at Cranston and to the U. S. Naval Air Station, Quonset Point, Rhode Island. The party met at the Dedham Court House, and travelled by private autos to the Cranston City Hall, where Mr. Ralph W. Horne of Fay, Spofford & Thorndike, Consulting Engineers, gave a brief description of the new sewage disposal plant. The mayor of Cranston also spoke and welcomed the members of the B. S. C. E. to the city. Following an inspection of the treatment works the party proceeded to the Brick Oven in Howard, R. I., where 51 members enjoyed a very fine luncheon which had been arranged by the committee, Chairman Coffin and Past Chairman Joy. After luncheon the party proceeded to the Naval Air Station at Quonset, where the party was joined by a considerable number of others who had gone there direct. The party was conducted through the air station by Lieut. Edwin W. Southworth, Assistant to the Officer-in-Charge of Construction, and after viewing the great work which has been accomplished here in a relatively short space of time, the group returned homeward having spent both a profitable and enjoyable day.

WALTER E. MERRILL, *Clerk*.

OCTOBER 1, 1941.—A regular meeting of the Sanitary Section was held this evening at the Society rooms, attended by thirty-five members and guests, preceded by a supper at Patten's Restaurant attended by twenty-six persons.

The meeting was called to order at 7:00 P.M. by the Chairman, George W. Coffin.

The Chairman introduced the speaker of the evening, Mr. J. R. Snell of Fay, Spofford & Thorndike, whose subject was "Water Supply in Venezuela." Mr. Snell brought out the scenic beauties of this South American country and also some of the handicaps under which an American must work. He described his experiences connected with the introduction of safe water supplies for several of the larger cities. In Caracas, with a population of 250,000, the water supply is obtained far below the surface; each house has a small tank, and the water is turned on only two hours daily. In conclusion Mr. Snell showed motion pictures of Venezuela. The meeting adjourned at 9:30 P.M., after giving Mr. Snell a vote of thanks for his very enjoyable talk.

WALTER E. MERRILL, *Clerk*.

Designers Section

OCTOBER 8, 1941.—A regular meeting of the Designers' Section was held this evening in the Society's rooms. Chairman John B. Wilbur called the meeting to order at 6:55 P.M.

The Clerk's report of the last meeting was accepted as read, after which an announcement of the proposed Student Night Meeting (held jointly by the Boston Society of Civil Engineers and A. S. C. E.) was made.

Professor Wilbur then introduced the speaker of the evening, Mr. James H. Carr, Jr., Structural Engineer of the Timber Engineering Company, Washington, D. C., who spoke on "Recent Developments in Timber Engineering." Mr. Carr reviewed the history and develop-

ment of timber engineering after which he briefly listed "information available" for use in timber design, and then—by the aid of slides—described types, applications and possibilities of timber construction through the correct use of modern connectors.

A long and interesting discussion followed the talk. The meeting was adjourned at 8:20 P.M. Attendance 46.

HERMAN G. PROTZE, *Clerk.*

NOVEMBER 12, 1941.—A regular meeting of the Designers' Section was held this evening in the Society's rooms. Chairman John B. Wilbur called the meeting to order at 7:00 P.M.

After the Clerk's report of the last meeting was accepted as read, Dr. Wilbur introduced the speaker of the evening, Mr. Edmund M. Burke, Construction Engineer, Bethlehem Steel Company Shipbuilding Division, Quincy, Mass., who talked on "Plant Facilities Expansion at Fore River Shipyard." Mr. Burke reviewed the salient design and construction features of the present \$18,500,000 expansion program at Fore River to give us conception of the gigantic problems, plans, methods, and organizations met and employed in completing this complicated and heterogeneous project on schedule. A very excellent series of lantern slides helped indicate the construction sequence of the work.

The meeting was opened to discussion after the talk and adjournment was at 8:30 P.M. Members and guests in attendance at the meeting totaled forty-one.

HERMAN G. PROTZE, *Clerk.*

Northeastern University Section

OCTOBER 3, 1941.—The first meeting of the Northeastern University Section for the school year 1941-1942 was held in room 44-OR on October 3, 1941.

President Richard Sutliff opened the meeting at 7:00 P.M. The Clerk's re-

port was read and approved. Acting Treasurer, George Hankinson, made the announcement that dues for the coming year were payable.

President Sutliff then announced the forthcoming Student Night of the B.S.C.E. and the A.S.C.E. which will be held this year as usual at M.I.T. on Wednesday evening, October 15. Following this, the President discussed the trip which is being planned for society members to visit the Franklin Falls Dam in New Hampshire.

After this business of the meeting was performed, the President introduced the speaker of the evening, Professor Gordon M. Fair of the Graduate School of Engineering at Harvard, whose subject was "Sanitation Southern Style".

Professor Fair has made an extended tour of the Southern states in an attempt to survey and study from a sanitary engineer's point of view the three most prevalent diseases of the South: malaria, hook worm, and typhus. The incidence as well as the methods of combating these diseases were discussed.

The control and elimination of malaria as a menace must be effected by attacking the carrier of the disease, the mosquito, and this can be accomplished in several ways, stated Professor Fair. Draining or filling is effective where this is applicable, but powdering or oiling the surface, while generally not permanent, can be utilized on a much larger scale. Professor Fair spoke about the project undertaken by the Federal Government to screen and mosquito-proof the dwellings of southern homesteaders.

The subject of hookworms was next discussed by the speaker who treated this more briefly than the topic of malaria.

The professor treated the disease of typhus lastly, and brought to the attention of the audience the outstanding problem with respect to this disease and methods for the prevention of pollution and transmission of infection.

Professor Gordon M. Fair was given

a rising vote of thanks by the audience, and the meeting adjourned at 8:45 P.M.

There were fifty-two in attendance at the meeting; twenty were present at supper which was held at the Old France restaurant preceding the meeting.

IRVING T. BERKLAND, *Clerk*.

OCTOBER 23, 1941.—A noon meeting of the Northeastern University Section was held today in room 201-S.

The meeting was called to order at 1:00 P.M. by the President, Richard D. Sutliff. The Clerk's report was read and accepted.

An announcement of the third annual competition for the Daniel W. Mead Student Prize for a paper on Ethics was made by the president. The topic for the competition which closes July 1, 1942, is "Ethical Standards and How Best They Can be Developed."

A trip which is being planned to Franklin Falls for the purpose of viewing the earth fill dam was discussed briefly.

Announcement was next made of the new members of the Student Chapter, Carl Paladino and F. J. Coughlin.

President Sutliff then introduced the speaker, Norman S. Crossley, who spoke on "Construction of Reinforced Concrete Drawbridge".

Mr. Crossley discussed the preliminary survey work, the soundings on the center line of the bridge bent location, the driving and jetting of the piles, and the deck construction of the trestle, all of which phases of the job were performed by utilizing the old structure. The trestle floor which was precast in three sections rested at a level of ten feet above the surface of the water. This structure replaced a 850 foot wood structure. Mr. Crossley concluded his talk by answering questions that arose over the construction of the bridge. A rising vote of thanks was given the speaker by the thirty-four who were in attendance.

The meeting adjourned at 1:55 P.M.

IRVING T. BERKLAND, *Clerk*.

NOVEMBER 7, 1941.—An evening meeting of the Northeastern University Section was held this evening in room 44 OR.

The meeting was called to order at 7:15 P.M. by President Richard D. Sutliff. The Clerk's report was read and accepted.

Announcement was made of two new members of this Student Chapter, Joseph Capone, Jr., '43 and Edward Cummings '45.

Professor Emil A. Gramstorff explained to those in attendance the significance of the letter which this chapter of the A.S.C.E. received as commendation for its record of outstanding activities and accomplishments.

The speaker of the evening, Mr. Louis H. Berger, President of C. L. Berger & Sons, Inc., manufacturers of engineering and surveying instruments, was then introduced by President Sutliff.

Speaking on "Simplicity of Design, Materials Suitable for Construction, and the Proper Care of Engineering and Surveying Instruments", Mr. Berger stated that simplicity triumphs over complexity in the design of surveying instruments, for the engineer or surveyor must not only be able to adjust his instruments, but he must be able to make the minor repairs which are frequently necessary when working in remote sections of the country.

There are five essentials which contribute to the accuracy and satisfactory use of surveying and engineering instruments, which are as follows:

(1) The materials used in the construction must be of a high grade.

(2) The workmanship must be of as high a quality as the materials.

(3) The assembly must be comparable to that of the workmanship found in the machining of parts.

(4) Careful tests must be run before delivering the instrument.

(5) Proper care of the instrument by the purchaser.

Mr. Berger told of the transits which he constructed specially for use by the United States and the Canadian Governments where lightness of instrument was of prime importance. These instruments, which were made of aluminum, were to be used by explorers who expected to be travelling over difficult terrain.

Having built surveying instruments for both the Perry and Byrd expeditions, Mr. Berger was able to speak with authority on the subject of using transits in the frigid zones. He said that a great deal of difficulty was experienced in the differential contraction of adjacent moving parts of the transit due to the extremely low temperatures experienced by these polar explorers. This problem was overcome by the use of suitable metals.

It is also necessary, said Mr. Berger, to remove all oil from the moving parts of the transit, as this coagulates making the instrument practically useless. In one transit, said the speaker, hard rubber or bakelite hooks were attached to the metallic screws to prevent freezing of the bare hands to the metal.

Mr. Berger showed several enlarged photographs depicting the conditions which the explorer encounters in attempting to successfully make observations by use of surveying instruments. The speaker was given a rising vote of thanks by the twenty-nine who were in attendance.

The meeting which was preceded by a dinner at the Old France Restaurant attended by twenty-one, was adjourned at 9:00 P.M.

IRVING T. BERKLAND, *Clerk.*

DECEMBER 4, 1941.—A noon meeting of the Northeastern University Section was held today in room 210-S. The meeting was called to order at 1:00 P.M. by the Vice Chairman, Charles B.

Swift. The Clerk's report was read and accepted.

Announcement was made and the members were urged to prepare papers for three competitions: namely, the Boston Society of Civil Engineers' \$15.00 book prize; the American Society of Civil Engineers' \$25.00 payment towards membership in the parent society prize for a paper to be presented at the New England Convention at Norwich University, and the American Society of Civil Engineers' Daniel W. Mead Student Prize for a paper on Ethics.

Announcement was next made of the new members of this Student Chapter, Elmer Smith and David Bornstein.

Vice Chairman Swift then introduced the speaker for the meeting, John Cusack '44, who spoke on "Embankment Control at Franklin Falls Dam."

Mr. Cusack discussed the various methods used to extract and test soil samples taken at the dam. He told how after being tested the soils were classified into groups which went to make up the impervious core, the selected previous layer and the plain pervious layer. The dam has a width of 1830 feet at the bottom and 35 feet at the top. It is approximately one-half mile in length. The impervious core will be brought to within five feet of the top elevation. A road will be provided at the top for vehicular traffic. The dam is the largest of its kind, that is rolled-fill earth, east of the Mississippi River. The purpose of its construction is for flood control in New Hampshire.

Mr. Cusack concluded his talk by answering questions proposed by the members.

A rising vote of thanks was given Mr. Cusack by the forty-four who were in attendance. The meeting adjourned at 1:45 P.M.

JOSEPH J. CAPUTI, *Clerk.*

DECEMBER 5, 1941.—A meeting of the Northeastern University Civil Engineering Society was held this evening in room 440 Richards Hall. Prior to the meeting the guest speaker, Mr. Robert A. Prowse, was the guest of the Society for dinner at the Old France Restaurant.

The meeting was called to order at 7:15 P.M. by the Vice Chairman, Charles B. Swift. The Clerk's report was read and accepted.

Vice Chairman Swift then introduced the speaker, Mr. Prowse, who spoke on "Designing Time Two Hundred Years". With his talk the speaker showed several colored slides which he has accumulated in the course of his position as an engineer for the Highway Bridge Department of the State of New Hampshire. These depicted the growth of bridge design in the past two centuries from covered timber bridges to modern steel spans and modern stone bridges.

In his talk he pointed out that the New Hampshire bridges were constructed to fit the surrounding terrain and that they were constructed from granite quarried in the near vicinity if it was available.

The speaker discussed some of the problems with which the Highway Bridge Department has had to cope, such as the diverting of fumes from the stack of a railroad engine passing under a bridge, so that they would not stain the attractive finish of the face stone; the erecting of bridges which had been washed out by the last flood; and the ever present problem of remodeling old structures so that they will be serviceable.

Mr. Prowse concluded his talk by answering questions which arose over the designing and maintaining of bridges.

A rising vote of thanks was accorded Mr. Prowse by the forty-eight who were in attendance.

The meeting adjourned at 9:00 P.M.

JOSEPH J. CAPUTI, *Clerk*.

APPLICATIONS FOR MEMBERSHIP

[January 20, 1942]

The By-Laws provide that the Board of Government shall consider applications for membership with reference to the eligibility of each candidate for admission and shall determine the proper grade of membership to which he is entitled.

The Board must depend largely upon the members of the Society for the information which will enable it to arrive at a just conclusion. Every member is therefore urged to communicate promptly any facts in relation to the personal character or professional reputation and experience of the candidates which will assist the Board in its consideration. Communications relating to applicants are considered by the Board as strictly confidential.

The fact that applicants give the names of certain members as reference does not necessarily mean that such members endorse the candidate.

The Board of Government will not consider applications until the expiration of fifteen (15) days from the date given.

For Admission

RALPH E. FADUM, Winchester, Mass. (b. July 19, 1912, Pittsburgh, Pa.) B.S. in Civil Engineering, University of Illinois, 1935; M.S. in Engineering, Harvard University, 1937; D. Sc. at Harvard University, 1941. Experience: 1935, Assistant to E. B. Strowger, Hydraulic Engineer, Niagara Hudson Power Corporation, Buffalo, New York; summer of 1936, assistant to W. P. Creager, Consulting Engineer, Buffalo, New York; 1937, Structural Design, Chicago Bridge & Iron Company, Greenville, Pa.; 1938, Foundation Studies, Cram & Ferguson, Boston, Mass.; 1939, same as Summer of 1938; 1940, Foundation Studies, Dry Dock Association, Portsmouth, Virginia; 1941, Foundation

Studies, Jackson & Moreland, Boston, Mass. Refers to *A. Casagrande, A. Haertlein, L. S. Homer, H. A. Mohr, K. Terzaghi.*

FREDERICK S. GIBBS, Waban, Mass. (b. July 28, 1905, Carthage, New York.) Machinist apprentice—Ryther & Pringle Company, Carthage, N. Y., during High School years. June, 1922—June, 1923, Engineer's assistant, T. F. Breslin Construction Co., Watertown, New York; June, 1922—September, 1924, Engineer's assistant, U. G. I. Construction Company, Beavers Falls, New York; September, 1924—June, 1929, undergraduate, Syracuse University, graduated, C. E. (Member Tau Beta Pi); June 1929—January, 1930, Mechanical & Structural Design—Koppers Company, Pittsburgh, Pa.; January 1930 to date, Civil & Sanitary Engineer with Wallace & Tiernan Company, Inc., located at Syracuse, New York, 1930 to 1936; and at Boston from 1936 to date. Refers to *E. S. Chase, S. E. Coburn, A. Harding, E. D. Mortenson, W. H. Sears, A. D. Weston.*

WILLARD F. JACKSON, Brockton, Mass. (b. May 2, 1876, Brockton, Mass.) Massachusetts Institute of Technology 1896-1898, Architectural course. Junior Draftsman with Arthur H. Bowditch, architect of Boston, 1898-1900. Senior draftsman with Arthur F. Gray, architect and mill engineer of Boston, 1900-1902. Transitman and designing architect with city engineer of Brockton on water supply construction, May, 1902-August, 1904; Designing Architect, and assistant superintendent of construction in charge of cost keeping with Dodge & Day, Philadelphia, 1905-1908; In private practice 1908 to 1918 in Brockton and Boston; Purchasing agent with Fay, Spofford & Thorndike of Boston, May 1918 to February 1919; Construction engineer in charge of estimating with C. A. Batson Company of Brockton, 1921-1929; salesman

for building materials 1929-1934; at intervals 1934-1940 with the city engineer's department of Brockton as draftsman, transitman, and chief of party on sewer and drainage construction and topographical surveys. Inspector of sewer construction with Frank A. Barbour, at Fort Devens, November, 1940-March, 1941. With Fay, Spofford & Thorndike of Boston, May, 1941 to date as estimator and later on progress reports. Refers to *W. M. Campbell, G. W. Coffin, W. L. Hyland, M. H. Mellish.*

ARPAD A. WARLAM, Cambridge, Mass. (b. March 1, 1909, Budapest, Hungary.) Entered the Royal Hungarian University of Technical Sciences in Budapest in 1927, graduated in Civil Engineering in 1931, and received diploma of "Certified Civil Engineer", in 1932. Enrolled for two years study in Economics and received diploma of "Certified Economist" in 1933. Through the summer of 1933 worked as engineer for the Hungarian General Road Construction Company, in charge of office and field work in connection with concrete paving of a 20 ton section of the "London Istanbul" transcontinental highway and some streets in Budapest. October, 1933, received a scholarship at the University of California and studied engineering and economics there until the summer of 1934, when an opportunity presented itself to acquire some more experience in road construction in the employ of the Highway Department of State of Washington. In the autumn of 1934, studied at the University of Washington and did some research in Soil Mechanics. In 1935 entered Harvard Graduate School of Engineering and completed a years graduate work for the M.S. degree; returned to Budapest in 1936, taking a position of an assistant at the Technical University. From autumn of 1936 to spring of 1940, employed by the Ministry of Commerce and Communication of Hungary, first as a Junior, later as assistant engineer in charge of vari-

ous construction projects. In 1940, returned to Harvard and at present am engaged in research in Soil Mechanics. Refers to *A. Casagrande, A. Haertlein, D. Taylor, K. Terzaghi.*

PAUL A. WIRTH, Mansfield, Mass. (b. April 12, 1902, Revere, Mass.) Revere High School, 1 year, technical course, Revere Evening School, 3 years, technical course. Certified for Home Study in Mathematics, Physics, and Engineering drawing. University extension course in blue print reading and estimating. Home study work in surveying. Experience: January-March, 1919, Junior draftsman, Revere Rubber Company, Chelsea, Mass.; April-December, 1919, draftsman Penn Metal Company, Boston; April-December, 1920, draftsman, Condit Electric Mfg. Company, South Boston, Mass., January, 1921-January, 1922, draftsman, General Electric Company, Lynn, Mass., January, 1922-December, 1927, draftsman and estimator, Vogt & Company, Cast Stone manufacturers, Malden, Mass., December, 1927-September, 1928, draftsman and estimator, Bianchi Art Stone Company, Quincy, Mass., September, 1928-August, 1932, draftsman, estimator with Alex Thomson, Inc., Providence, R. I., August, 1932-April, 1936, private work, drawing plans, making surveys and some building construction, April-July, 1936, Senior Engineering Aide, Massachusetts Department of Public Works, Greenfield, Mass., October, 1936-September, 1937, February, 1938-November, 1940, assistant Civil Engineer, Town of Mansfield, September, 1937-February, 1938, designer and checker, New England Power Service Company, Boston; Engineer for Highland Sand & Gravel Company, West Roxbury, layout and construction of new plant. July-September, 1941, assistant engineer with George P. Carver Company, Boston, field engineering. At present assistant engineer with Howard M. Turner of Boston on hydro-electric

valuation surveys. Refers to *H. Brack, G. W. Coffin, H. D. Dresser, C. M. Durgin, R. E. Petterson.*

Transfer from Grade of Junior

ROBERT J. GREER, Medford, Mass. (b. August 14, 1913, East Boston, Mass.) Graduated from Massachusetts Institute of Technology, June, 1935, S.B. degree in Electrical Engineering. Experience: June, 1935 to March, 1939, with U. S. Engineer Department, Cape Cod Canal, as Inspector of Waterway Construction and as Civil Engineering Aide, on Hydrographic Survey and drafting work and dredging. March, 1939, to date as Junior Hydraulic Engineer for U. S. Geological Survey, Water Resources Branch at Boston, Mass., engaged in stream gaging and supervision of construction of stream gaging stations and control weirs. Refers to, *M. A. Benson, W. L. Isherwood, Jr., G. K. Wood, H. B. Kinnison.*

KENNETH F. KNOWLTON, Beverly, Mass. (b. May 22, 1913, Natick, Mass.) Graduated from Northeastern University in 1935, B.S. Degree in Civil Engineering. Experience: Senior Engineering Aid, Massachusetts Department of Public Health, August to September, 1935; June to November, 1936; and July 1939 to September, 1941. Resident Engineer in charge of operation of Bristol, R. I., sewage treatment plant under Mr. H. K. Barrows, January to November, 1937. Technical Department Assistant, Cabot Carbon Company, Pampa, Texas, from February, 1938 to May, 1939; draftsman for Crandall Dry Dock Engineers, June and July, 1939; the period from February to June, 1937, was devoted to study in Sanitary Engineering at the Graduate School of Engineering at Harvard. From September, 1941, to the present, employed as Superintendent and Chemist by the Salem and Beverly, Mass. Water Supply Board. Refers to *C. O.*

Baird, A. J. Burdoin, S. M. Ellsworth, W. E. Merrill, R. M. Soule.

WILLIAM S. MARINER, Dover, Mass. (b. April 6, 1906, New York, N. Y.) Studied at the Harvard Engineering School, 4½ years. Summer work as rodman and instrumentman on topographic surveys and hydroelectric construction. Experience, 1928-1931, instrument man and in charge of field testing laboratory for New England Public Service Company during construction of hydroelectric development (Wyman Station) Bingham, Maine; 1931-1934, safety engineer, Liberty Mutual Insurance Company, promotion of industrial and construction safety; 1936-1937, assistant engineer, Metcalf & Eddy, sewer construction in open cut and tunnel; water treatment plant design; 1937-1938, assistant engineer, Braintree Sewer Dept., sewer design, construction and assessments; 1938 to date, assistant engineer, Metcalf & Eddy, surveys for and design of sewerage works; design of water distribution systems and plants for treatment of water and industrial wastes; specifications; estimates; resident engineer on construction of sewers and sewage treatment plants. Refers to *E. S. Chase, F. A. Marston, A. L. Shaw, J. P. Wentworth.*

JOHN S. ROSS, Roslindale, Mass. (b. July 18, 1912, Roslindale, Mass.) April, 1937, to December, 1937, detail draftsman of General Electric Plant, Lynn, Mass.; December, 1937, to May, 1938, timekeeper for J. J. Sullivan Company, Plumbing & Heating contractors, Boston, Mass.; May, 1938, to October, 1938, engineering work on concrete and steel building for Boston Elevated Railway; October, 1938, to November, 1940, chief of engineer party on high pressure aqueduct line (Metropolitan District Commission); November, 1940, to February, 1941, construction inspector for F. A. Barbour Company at Camp

Devens, Mass.; February, 1941, to June, 1941, engineer for C. J. Maney Company, Inc.; June to September, 1941, engineer on job during driving of Raymond piles at Watertown Arsenal for E. J. Rappalli Company. September, 1941 to present, layout and general construction inspection on three large buildings at Watertown Arsenal for J. R. Worcester & Company. Refers to *C. O. Baird, F. A. Barbour, C. S. Ell, E. A. Gramstorff, T. R. Worcester.*

Transfer from Grade of Student

ALAN K. WILLARD, Nashua, New Hampshire. (b. March 13, 1913, Nashua, N. H.) Graduated 1935 from Northeastern University, B.S. degree in Civil Engineering. Experience, from graduation to January, 1936, as engineer with Nottingham Surveyors, Hudson, N. H., construction layout and land surveys; January, 1936, to present date with Tennessee Valley Authority under Engineering Aide; Jr. Engineering Aide; Assistant Engineering Aide; Engineering Aide; Jr. Civil Engineer, reservoir surveys and topographic mapping, principally by aerial photography. Refers to *C. O. Baird, A. E. Everett, E. A. Gramstorff, K. F. Knowlton.*

PENNETH M. CLINE, Roxbury, Mass. (b. November 12, 1917, Boston, Mass.) Graduated from Northeastern University in 1940, receiving B.S. degree in Civil Engineering. Experience, 1936-1939, summers and school cooperative periods, H. E. Cline Construction Company, lines and grades; 1939-1940, summer and school cooperative periods, assistant to engineer on building construction. At present, engineer and superintendent of construction, H. E. Cline Construction Company, Boston, Mass. Refers to *C. O. Baird, E. A. Gramstorff, G. H. Meserve, Jr., A. E. Everett.*

HENRY G. SEELEY, South Boston, Mass. (b. May 26, 1916, Boston, Mass.) Graduate of Northeastern Uni-

versity, 1940, B.S. degree in Civil Engineering. Experience, 1939-1940, transitman and inspector, New York, New Haven and Hartford, Railroad; 1940-1941, transitman and layoutman with Gibbs & Hill, Inc., Consulting Engineers, New York; 3 months during 1937 with L. E. Perkins, Hingham, Mass., as rodman; 3 months of 1940 with Pascone Brothers, Bridgeport, Conn., as transitman and layout man. At present with Jackson & Moreland, Boston, Mass., as draftsman, computer, design. Refers to C. O. Baird, J. L. Bean, A. E. Everett, E. A. Gramstorff.

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DEATHS

- CHARLES F. FITZ July 11, 1941
 T. T. HUNTER HARWOOD
 November 21, 1940

BOOK REVIEW*

During 1940, about forty books were published on the subject of astronomy. On the face of it, that would seem sufficient for some time to come. Nevertheless, the Blakiston Company of Philadelphia is gambling that the public can absorb still more books, for this publisher is producing nine books on astronomy during 1941. All of these are written by members of the staff of Harvard College Observatory in Cambridge, Mass. Four titles are now available—

THE MILKY WAY by Bart J. Bok and Priscilla F. Bok (204 pp., Ill., \$2.50)
 EARTH, MOON, AND PLANETS, by Fred G. Whipple (293 pp., Ill., \$2.50)
 BETWEEN THE PLANETS, by Fletcher G. Watson (222 pp. Ill., \$2.50)

THE STORY OF VARIABLE STARS, by Leon Campbell and Uigui Jacchia (226 pp., Ill., \$2.50)

Although this is only the beginning, it is an indication of what is to come—a complete series of handy volumes, each volume treating one phase of astronomy, and each is written by an authority in his special field. These are the most up-to-date books on astronomy. They open the vast expanse of the universe, making it more real by the more than 425 illustrations.

The Boks invite one to a "tour along the road to the heaven of the Greeks." The tour begins in their home where they show you maps and photographs of the things you will explore. They do not forget that you want to see their workshop and how they go about determining the vast distances of space and its contents—their problems and what they are doing about them.

In the confines of their laboratory they show how the astronomer attacks his problems. Before you know it you

*By R. Newton Mayall, Landscape Architect and Engineer, 115 Newbury Street, Boston, Mass.

are on speaking terms with whirling galaxies, bright and dark nebulae, interstellar gases, and many other fascinating things with which the astronomer deals. Inset in the back cover are two beautiful photographic maps of the Milky Way, as seen from both the southern and the northern hemispheres. One of the nicest features of this book is the constant reference to those astronomers who have been responsible for many of our present day concepts of the universe, and those who are working on new theories; and best of all there are innumerable photographs of these men. In this way the Boks leave you with the feeling that you have met these people, talked with them, and found them good company.

Whipple feels there is a lot about the Earth, Moon, and Planets you ought to know. At least I know of no other book where one can get so much information about the planets in so short a time. He proceeds in a logical, straightforward simple manner to divorce these objects from any mystery. He tells what is known about their origin, how they are weighed, and just about all that is known about these children of the sun—knowledge that is based upon accepted scientific methods of research, not on superstition. How many times have you wondered what some particular bright star is in the sky? Nine cases out of ten it is a planet. One of the most useful features of this book is a star map and a table, by means of which one can find the position of the planets for any night from now until 1970.

Between the planets are comets, little planets (asteroids), and meteors. Watson summarizes the history of these objects and introduces one to an amazing amount of research that has been and is being carried on in this field of astronomy. Meteors are our only physical contact with celestial bodies, there-

fore they form an important link in the study of astronomy. All that is known about meteors, asteroids and comets will be found within the covers of this book. Dr. Watson has not forgotten to mention the work of the amateur who spends his evenings charting or photographing meteors and searching for comets.

The Story of Variable Stars, by Campbell and Jacchia, further accentuates the widespread activity of amateur astronomers—a large group that has been of great aid to the professional astronomer. Whether you know it or not, there are hundreds of amateurs watching stars that vary in brightness. Campbell and Jacchia weave an interesting story about these stars. Their book tells of the history of variable stars, how they are observed, what is done with the observations, and states the various theories concerning them. Among the most important stars in the sky are the so-called Cepheid variables, which enable the astronomer to determine distances with very little trouble.

Some of our well known stars such as Mira, Algol, and even the mariner's guide—the North Star—are variable. Mira is in the constellation of Cetus (The Whale). Watch the stars that form this group—watch them whenever you are out at night. Soon you will find a star missing, and if you continue to watch this part of the sky, the missing star will reappear. Mira continues this disappearing act about every 330 days. For an interesting evening's reading pick up *The Story of Variable Stars*.

These books should be in the home and in the school, where the children can get a correct picture of the astronomer. The authors of this series really take one behind the scenes and show what they have to deal with, how they use their material, and what they expect to do with it.

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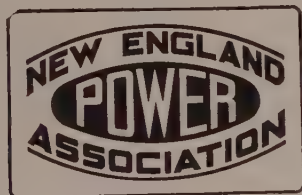
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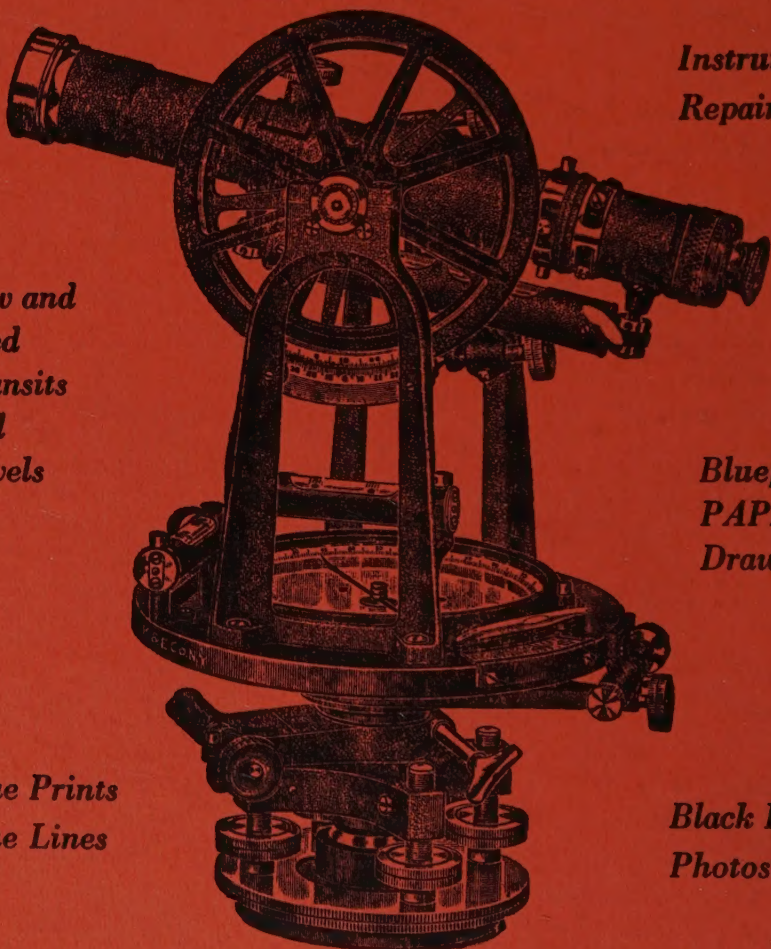
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